THE TAMILNADU DR. M.G.R. MEDICAL UNIVERSITY

CHENNAI, TAMILNADU

ACCURACY OF PULMONARY ARTERY ACCELERATION TIME DERIVED BY DOPPLER ECHOCARDIOGRAPHY IN PREDICTING PULMONARY ARTERY PRESSURES

Dissertation submitted for DM

(Branch II – Cardiology)

August 2013

CERTIFICATE

This is to certify that this dissertation titled "**ACCURACY OF PULMONARY ARTERY ACCELERATION TIME DERIVED BY DOPPLER ECHOCARDIOGRAPHY IN PREDICTING PULMONARY ARTERY PRESSURES** ", submitted by Dr.A.Jegadeeswari, to the faculty of Cardiology, The Tamilnadu Dr.M.G.R.Medical University, Chennai in partial fulfillment of the requirement for the award of DM degree, Branch II [Cardiology] is a bonafide research work carried out by her under my direct supervision and guidance.

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DECLARATION

I, **Dr.A.Jegadeeswari**, solemnly declare that the dissertation titled "**ACCURACY OF PULMONARY ARTERY ACCELERATION TIME DERIVED BY DOPPLER ECHOCARDIOGRAPHY IN PREDICTING PULMONARY ARTERY PRESSURES** " has been prepared by me. This is submitted to The Tamilnadu Dr.M.G.R.Medical University, Chennai, in partial fulfillment of the regulations for the award of DM degree, Branch II [Cardiology].

Madurai. **Dr.A.Jegadeeswari**

Date:

ACKNOWLEDGEMENT

My sincere thanks to our Dean, Prof. Dr. N. Mohan, M.S., for permitting me to use the facilities of Govt. Rajaji Hospital and Madurai Medical College to conduct this study.

I am indebted to my beloved Professor and Head of the Department of Cardiology, Prof. Dr.R.A.Janarthanan, M.D.,D.M., who had guided me throughout the conduct of the study and also during the postgraduate course. I thank him profusely and sincerely.

My sincere thanks to my Prof. Dr. A.S. Arul, M.D.,D.M., Addl. Professor of Cardiology, for his valuable support throughout the study and also in the D.M. course.

I shall ever remain in gratitude to my teachers, Prof. Dr. V.A. Amuthan, M.D.,D.M.,FACC, and Prof. Dr. S. Murugan,M.D.,D.M., retired Professors of Cardiology, Govt. Rajaji Hospital and Dr. S.Balasubramanian,M.D.,D.M., and Dr. R.Aravazhi, M.D.,D.M., former Asst. Professors of Cardiology, Govt. Rajaji Hospital.

Knowledge and kindness abound my beloved teachers, Dr. S. Naina Mohammed, M.D.,D.M., Dr. N.Ganesan, M.D.,D.M., Dr. G.S. Sivakumar, M.D.,D.M. and Dr. S.R. Veeramani, M.D.,D.M.. I owe them a lot and sincerely thank them.

I am thankful to all my colleagues for their valuable support to help complete the study.

Above all, I am indebted to all the patients who participated in the study. Without them, this work would not have been possible. My sincere thanks to them.

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INTRODUCTION

Two decades ago pulmonary hypertension (PH) was seen as a serious illness with a survival of 2.8 years from its diagnosis. Significant progress has been made in this field in the last ten to fifteen years in the understanding of the pathophysiology and also the treatment of PH. In the past, even though physicians diagnosed PH, treatment of this condition was not rewarding and patients almost always succumbed to the disease. The discovery of prostacyclin by Sir John Vane has since made a revolution in the treatment of PH[1].

PH is a disease that results from reduction in the quantity of blood flowing across the pulmonary circulation, that causes an increase in pulmonary vascular resistance (PVR) and ultimately to right ventricular failure[2] Excessive proliferation of the endothelial lining cells of the pulmonary vasculature and reduced apoptosis of the same leads reduction in the luminal cross sectional area of the pulmonary arterial tree. This results in increased pulmonary vascular resistance(PVR). Abnormal and inappropriate vasoconstriction is also implicated in about 20% of patients.[3,4]

PH occurs in many different clinical conditions and the hemodynamic abnormality leads to right ventricular (RV) pressure overload. The clinical disease producing PH, the type of vascular pathology and the severity of the lesions determine the natural history of PH, the clinical features and its potential reversibility: PH caused by chronic hypoxia is mainly due to muscularization of the small muscular pulmonary arteries. The endothelium is not much affected. Correction of hypoxia leads to reversal of PH. As

opposed to this, systemic sclerosis causing PH progresses relentlessly because the vascular pathology involves the intimal layer mainly, leading to vascular obstruction. And in pulmonary capillary hemangiomatosis, the main pathological lesions are seen in the pulmonary capillary bed.

Because of its great distensibility, large capacity, low resistance to blood flow, and the very modest amounts of smooth muscle in the small arteries and arterioles, usually the pulmonary circulation is not predisposed to become hypertensive. But when the total cross-sectional area of the pulmonary circulation is decreased by destruction of lung tissue or occlusive lesions in the resistance vessels, pulmonary arterial pressures rises. The degree of PH that develops is thus a function of the amount of the pulmonary vascular tree that has been affected or eliminated.

PH is the result of heart or lung disease, commonly. Although idiopathic pulmonary artery hypertension (IPAH) is uncommon, it is well recognized as a unique clinical entity where the intrinsic pulmonary vascular disease is free from the complicating features of PH contributed by diseases of the heart and/or lungs.

Mild PH can exist for a lifetime without becoming evident clinically. Native residents at a high altitude, in whom mild to moderate PH is due to sustained exposure to hypoxia, can adapt and function normally. When pulmonary hypertension does become manifest clinically, the symptoms tend to be nonspecific.

Patients with severe PH have a poor prognosis, in the absence of treatment. But the recent drugs used for the treatment of PH have shown a beneficial influence on the

survival rate in several recent meta analyses of trials[5]. The understanding of the disease pathways in PH have improved notably in the recent times. This has paved the way for newer therapeutic strategies: use of prostaglandins, inhibition of PDE-5 and the antagonism of endothelin receptors. In the near future, newer drugs which are now being tested in pre clinical studies may become available: inhibitiors of pyruvate dehydrogenase kinase, the antiapoptotic protein survivin, the serotonin transporter (5-HTT); several transcription factors (HIF-1 alpha and nuclear factor activating T lymphocytes [NFAT]), and also drugs that augment the voltage-gated potassium channel channels (e.g., Kv1.5). Other drugs for treatment of PH which are in their infancy of development include vasoactive intestinal peptide(VIP) and tyrosine kinase inhibitors. Administration of stem cells and angiogenic factors and drugs that target the mitochondrial dysfunction also have therapeutic promise in the future.

Normal Pulmonary Circulation

Structure

Just before birth, pulmonary and systemic arterial blood pressures are nearly equal at about 70/40 mmHg, with a mean of 50 mmHg. Immediately after birth, with the closure of ductus arteriosus and the initiation of ventilation, pulmonary arterial pressure rapidly falls to about one-half of systemic levels. After that, the pulmonary arterial pressures gradually reduce over several weeks to reach adult levels.

In some new born, the normal PH of the fetus fails to recede normally, as a result of either a developmental anomaly or a persistent increase in pulmonary vascular tone.

In such neonates, the persistent pulmonary hypertension and the RV failure may become life-threatening. Temporizing measures, like the use of inhaled nitric oxide (NO) or extracorporeal membrane oxygenation or surgical intervention , might be useful in reversing the pulmonary vascular abnormalities.

In normal adults at sea level, the small muscular arteries and arterioles in the lungs are thin-walled and have very little smooth muscle. But in the fetus or in the adult who has lived under hypoxic conditions (residents of high altitude), the media of the arterioles are more thick, and the muscle also extends distally into the precapillary vessels that are normally devoid of muscle - the precapillary vessels undergo "remodeling."

Endothelium and Endothelium–Smooth Muscle Interactions in the lungs

The endothelium is a semipermeable membrane that acts as a barrier between blood and the pulmonary interstitium. It has many other biologically important functions, the net effects of which are the processing of blood flowing through the lungs: it the synthesises and processes many vasoactive substances; modulates coagulation and thrombolysis; transduces many blood-borne signals; regulates cell proliferation; participates in immune reactions; engages in the local inflammatory reactions to injury; and also involves in angiogenesis. Endothelium is thus regarded as an organ with diverse metabolic and endocrine functions. Importantly, the largest area of endothelium in the body is contributed by the lungs.

The cells that make up the monolayered endothelial lining communicate with the smooth muscle cells in the medial layer through many biologically active substances. This interaction between the two layers of cells regulates the normal vasomotor tone. It also determines the response of the vasculature to the administration of vasodilating drugs used for the treatment of PH. Endothelial cell injury and the resultant proliferation of the intima and the hypertrophy of the underlying smooth muscle cells upset this normal interaction and alter the hemodynamics.

Pulmonary Hemodynamics in health

In adults, the value of normal pulmonary arterial pressure depends on the altitude. At the sea level, with a cardiac output of 5 to 6 L/min the normal pulmonary arterial pressure is about 20/12 mmHg, with a mean of 15 mmHg. At an altitude of 15,000 ft, the same cardiac output is associated with slightly higher pulmonary pressures. Pulmonary arterial pressures also tend to increase with age.

Table 1: Values for Normal Pulmonary Circulation at Sea Level and High Altitude

	Sea Level	**Altitude (~15,000 ft)**
Pulmonary arterial pressure mmHg	20/12, 15	38/14, 25
Cardiac output (Q), L/min	6	6
Left atrial pressure , mmHg	5	5
Pulmonary vascular resistance (mmHg/L)/min (R units)	1.7	3.3

Determination of PVR, calculated as : (pulmonary arterial pressure - LA pressure) / cardiac output, is a practical clinical method for assessing the pulmonary hemodynamics and for assessing vasoreactivity (the effect of administering a vasodilator agent in a patient with PH). Pulmonary artery wedge pressure is usually substituted for LA pressure.

In the normal lung, a considerable rise in cardiac output, increases pulmonary arterial pressure by only a few mm of Hg. But in PH, in which the recruitability of the pulmonary vascular bed and its distensibility are restricted by disease, pulmonary arterial pressure rises with even small increase in pulmonary blood flow. Changes in pulmonary blood volume are subtler than changes in pressure or flow in their hemodynamic effects.

Autonomic innervation of the pulmonary arteries plays a less significant role in regulating vasomotor tone than do local stimuli, particularly hypoxia. The mechanism of vasoconstriction due to hypoxia exerts is not fully understood but likely involves altered smooth muscle cell membrane ion channel activity. Acidosis potentiates this effect. Hypercapnia has a vasoconstictive effect on the pulmonary tree, by causing local acidosis. But it is a less powerful pulmonary vasoconstrictor agent.

Pulmonary Hemodynamics in disease

To differentiate among the various causes of PH, a detailed measurement of all the indices of pulmonary hemodynamics is important.

In PAH the pulmonary arterial pressures and the PVR are markedly elevated, while the pulmonary capillary wedge pressure, is usually normal. Congenital heart diseases, with left to right shunts are a common cause of PAH. Eisenmenger syndrome is characterized by PAH in its most advanced form of associated. A large left to right shunt present initially causes progressive pulmonary vascular disease and PAH, and subsequent reversal of the shunt.

The main alteration in PH due to left-heart disease is a significant increase in pulmonary wedge pressure; pulmonary arterial pressures show only a mild to moderate increase , and PVR is usually normal. Occasionally, PAP is markedly increased, and hence PVR is also increased. Diseases of the left heart like valvular diseases, LV systolic dysfunction, LVdiastolic dysfunction etc. can lead to PH.

In the presence of obstructive or restrictive lung diseases, PH is usually moderate, and PVR is moderately elevated. PCWP is normal or mildly elevated, in the absence of concomitant left heart disease. A similar pattern is seen in residents at high altitude, due to the effect of chronic hypoxia.

The pulmonary arterial pressures and PVR are elevated only to a mild to moderate degree in acute pulmonary embolism; PCWP is normal unless concomitant left-heart disease is present; the degree of elevation in PAP and PVR strongly correlate with the amount of pulmonary vascular obstruction.

Chronic pulmonary thromboembolic hypertension(CTEPH) occurs in about 4% to 5% of patients after an index episode of acute pulmonary embolism. The pulmonary

hemodynamics in CTEPH is similar to that of PAH; PAP and PVR are markedly increased, while PCWP is normal. To establish the diagnosis of chronic thromboembolic PH is of great clinical importance because it has got significant therapeutic implications : pulmonary endarterectomy in such cases reverses PH to a significant degree and results in marked clinical improvement.

DEFINITION OF PULMONARY HYPERTENSION

The fourth World Symposium on PH was held at Dana Point in 2008, where new cutoffs of mean pulmonary artery pressure (MPAP) for the diagnosis of PH were introduced. An MPAP < 21 mm Hg is normal; from 21 to 25 mm Hg is categorized as borderline, and >25 mm Hg is designated as PH. Correspondingly, echocardiographic maximum tricuspid regurgitant velocity (TRVmax) <2.5m/s is defined as normal, 2.5 to 2.8 m/s as borderline, and >2.8 m/s is defined as PH. Thus, PH has been defined as an increased MPAP more than 25 mmHg at rest as assessed by right heart catheterization[6,7].

Table2 : New cutoff values for the diagnosis of PH:

Invasive(MPAP)	Normal	< 21mm Hg
	Borderline	21 – 25 mm Hg
	Manifest	>25 mm Hg
Non invasive(TRVmax)	Normal	<2.5m/s
	Borderline	2.5-2.8m/s
	Manifest	> 2.8m/s

In a number of RCTs and registries of PAH the above mentioned values of MPAP has been used for randomising patients.[8,9] Recent analysis of the data available so far has revealed that the normal MPAP at rest is 14±3 mmHg, the upper limit of normal being 20 mmHg.[10,11] The significance of a value of MPAP between 21 and 24 mmHg is not clear. Patients with a PAP between 21 and 24 mm Hg need evaluation in future epidemiological studies. The definition of PH on the basis of a post exercise value of MPAP >30 mmHg as measured by RHC has not been backed by the published data so far, as the MPAP in healthy individuals reach much higher values.[10,12]

INCIDENCE

The estimated incidence of PH range from one to two cases per million in the general population[13]. The incidence of PAH in HIV infection and in portal hypertension has been estimated to be between 0.5% and 2%.[14] The familial form of PAH does not differ much from the sporadic form of the disease in the affected individual. There appears to be a trend for genetic anticipation whereby, the disease occurs early or is more severe in the subsequent generations.[15].

UPDATED CLASSIFICATION OF PH

Pulmonary hypertension (PH) is categorised into five groups:

- group 1, PAH;
- group 2, PH associated with left sided heart diseases;
- group 3, PH associated with lung disease and/or hypoxaemia;
- group 4,PH due to chronic thrombotic and/or embolic disease; and

- group 5, miscellaneous [16]

PAH (group 1):

This group comprises patients with pulmonary arterial hypertension.

Idiopathic and heritable PAH

IPAH is a disease characterized by sporadic occurrence, no family history of PAH and the absence of risk factors for PH. In contrast, in familial PAH there are mutations of the bone morphogenetic protein receptor type 2 (BMPR2) gene in about 70% of cases.[17]

Drug and toxin induced PAH

Anorexigens like fenfluramine and dexfenfluramine are also a rare cause of PAH. But drug induced PAH is decreasing in incidence as these agents are banned now. Selective serotonin reuptake inhibitors have also been found to cause PAH after their use in pregnant women.

PAH associated with connective tissue disease

Connective tissue diseases, more specifically, systemic sclerosis and systemic lupus erythematosus (SLE) are a well known cause of PAH. Interstitial lung disease is also common in these diseases and add to the severity of PAH in these individuals. In patients with systemic sclerosis, the prevalence of PAH is up to 16%. The prognosis for these patients with PAH associated with systemic sclerosis is particularly poor, compared to those patients diagnosed with systemic sclerosis who have no PAH. [18]

PAH associated with congenital heart disease

Congenital heart disease has an incidence of 1% in the general population. Fifteen percent of these patients eventually develop PAH. [19] Eisenmenger's syndrome is the most severe form of PAH in this group, as determined by the value of PVR, and is characterized by reversal of the initial left to right shunt, limitation of exercise capacity and cyanosis.

PAH associated with HIV infection

Patients with HIV infection have a prevalence of PAH of about 0.5%. [20] PAH is a well known complication of HIV infection. The highly active antiretroviral therapy has improved survival rates in patients infected by HIV. Hence nowadays the morbidity and the prognosis in patients with HIV infection is determined by the other non-infectious complications of HIV infection like PAH.

Portopulmonary hypertension

Portal hypertension is rarely associated with the development of PAH. This is known as porto pulmonary hypertension. The prevalence of PAH in patients with portal hypertension is 2 to 6%, as reported in a number of prospective studies. The presence and severity of cirrhosis of liver and the ventricular function determine the prognosis in such patients.[21]

PH due to left heart disease (group 2)

This category includes patients with PH due to left heart disease. Left ventricular myo-pericardial disease or left sided valvular heart disease cause increased left

ventricular end-diastolic pressure. This in turn causes increase in pulmonary venous pressure and PCWP, with resultant increase in pressure in the pulmonary arteries. The PVR is mostly normal and the transpulmonary gradient is <12 mm Hg in the majority of the patients in this group.

PH owing to lung disease and/or hypoxia (group 3)

Group3 includes patients with PH resulting from lung disease or hypoxia (interstitial lung diseases, Chronic obstructive pulmonary disease, and chronic hypoxia as a result of prolonged stay in high altitudes).

Chronic thromboembolic pulmonary hypertension (group 4)

At 2 years after an index episode of pulmonary embolism, the incidence of symptomatic CTEPH is found to be about 3.8%, as reported from prospective studies. The major pathology in CTEPH is the presence of organized residual thrombus in the proximal branch pulmonary arteries and also the occurence of small vessel arteriopathy. The pathology in the distal vessels in CTEPH is almost identical to that seen in PAH. Together , these lesions contribute to the progression of PH.[22]

PH with unclear etiologies (group 5)

Group 5 comprises several disorders associated with PH for which the etiology is either unknown or involves multiple factors. Myeloproliferative disorders like polycythaemia vera, chronic myeloid leukaemia and essential thrombocythaemia are listed in this group; metabolic disorders (Gaucher disease, type I glycogen storage disease, hypothyroidism, hyperthyroidism) and systemic disorders (sarcoidosis,

lymphangioleiomyomatosis, neurofibromatosis, Langerhan's cell histiocytosis) leading to PH are also included in this group.

Table 3: ETIOPATHOGENESIS AND PATHOLOGY OF PULMONARY HYPERTENSION

Suggested Mechanisms for Idiopathic Pulmonary Artery Hypertension	
Proposed Mechanism	**Evidence**
Early/sustained vasoconstriction	**Altered smooth muscle cell calcium kinetics** **Endothelial dysfunction**
Genetic predisposition	**Familial disease with gene locus identified** **Susceptibility with exposures, e.g., anorexigens, HIV, portal hypertension**
Pulmonary thrombosis/embolism	**Widespread occlusion of arteries/arterioles. Altered endothelial–platelet interaction**
Autoimmune disease	**Raynaud phenomenon and antinuclear antibodies common; female gender predilection**

Injury to the layers of the wall of the small muscular pulmonary arteries and the arterioles appears to be the common denominator in the pathogenesis of PH.[23] The intima of these vessels proliferates, in response to injury, leading to the endothelium changing from a single flat layer to a piled-up form that narrows the vascular lumen. Moreover, the media and the adventitia of the affected vessels too undergo hypertrophy.

The primary site of injury in IPAH remains unknown. An intrinsic defect in the function of the ion channel and in calcium homeostasis in the vascular smooth muscle has been proposed. The endothelial function is disturbed, leading to an altered production and handling of the endothelium-derived vasoactive substances, including nitric oxide, endothelin, and prostacyclin. These coupled with altered platelet-endothelial interactions predispose to intravascular thrombosis and release of growth factors, leading to an inexorable course of enhanced vascular reactivity, endothelial proliferation and remodeling and obliterative vasculopathy.

Many different etiologies lead to pulmonary hypertension. Ingestion of the anorexigens fenfluramine and dexfenfluramine have been demonstrated to markedly increase the risk of PAH; HIV infection also has been implicated; and ingestion of toxic oil had also led an outbreak of pulmonary hypertension in Spain ;. [23] An epidemic of PAH broke in Europe between 1967 and 1970 and was linked to the use of aminorex, an anorectic agent; this also raised the prospect of hereditary predisposition, because only 1 in 1000 persons who took the drug developed PH. Of late, the fenfluramines have also been associated with both severe PH and valvular heart disease.[23]

In recent past, PAH has been genetically linked in an increasing number of patients.[23] The hereditary pattern is autosomal dominant inheritance with incomplete penetrance. The gene responsible for the familial disease has been identified as the *BMPR2* (bone morphogenetic protein receptor 2) gene, which is a member of the transforming growth factor- family. One important insight provided by the study of the

families with familial PH is the diversity of pulmonary vascular lesions in the members of the same family.

The progressive reduction of the pulmonary arterial luminal cross sectional area gradually elevates PVR and leads to RV pressure overload, increased RV strain and RV failure. The small pulmonary arteries (40 and 100 µm diameter) and arterioles are the vessels which are mainly affected by the pathological process. The occlusive lesions affect more than one layer of the vasculature. Medial muscular hypertrophy predominates in some areas; in others, the intimal proliferation is more dominant. Added to this, evidence of inflammation may also be seen.

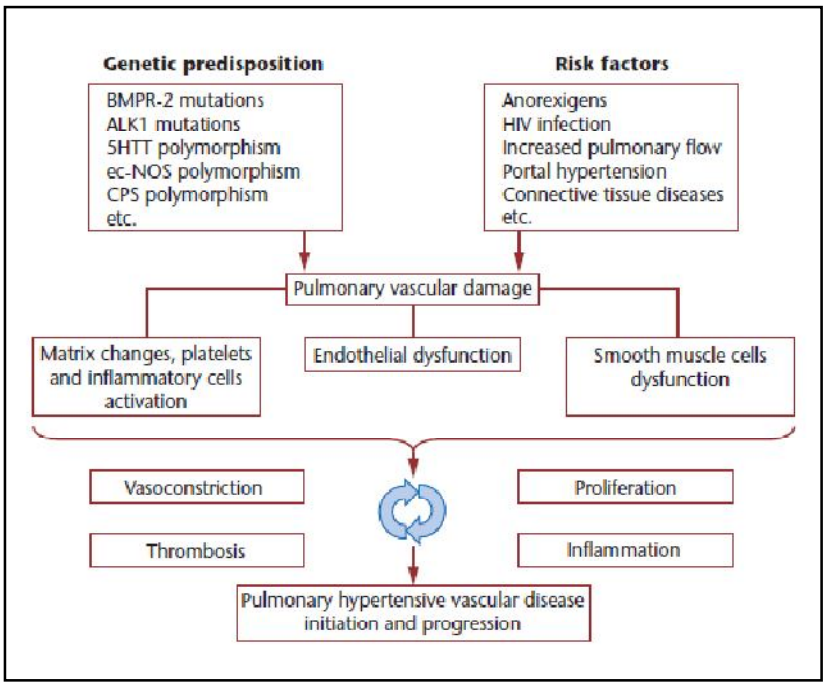
Histologic examination of the lung shows a variety of pulmonary precapillary lesions that are consistent with the diagnosis of PAH : angiomatoid lesions, plexiform lesions, concentric intimal fibrosis and necrotizing arteritis. Recent thrombi in small pulmonary arteries and arterioles are found at autopsy in patients with IPAH, more so in patients in whom the RV has failed. Although similar thrombi may not have initiated PH in IPAH, nevertheless, they are complicating factors that aggravate and exaggerate PH.

The pathological features of the PH groups.

Group 1, PAH: In this group, the small distal pulmonary arteries are the site of the pathological lesions. These are : intimal proliferative and fibrotic changes, medial hypertrophy, adventitial thickening, complex lesions (plexiform, dilated lesions), perivascular inflammatory infiltrates, and thrombotic lesions. Pulmonary veins are characteristically not affected.

Group 1' : PVOD is the main condition grouped in this subgroup. The disease involves the septal veins and pre-septal venules. The characteristic lesions are: muscularization of veins, occlusive fibrotic lesions, patchy capillary proliferation, alveolar haemorrhage, pulmonary oedema, inflammatory infiltrates, lymphatic dilatation and lymph node enlargement. Distal pulmonary arteries also demonstrate medial hypertrophy, intimal fibrosis, and uncommon complex lesions.

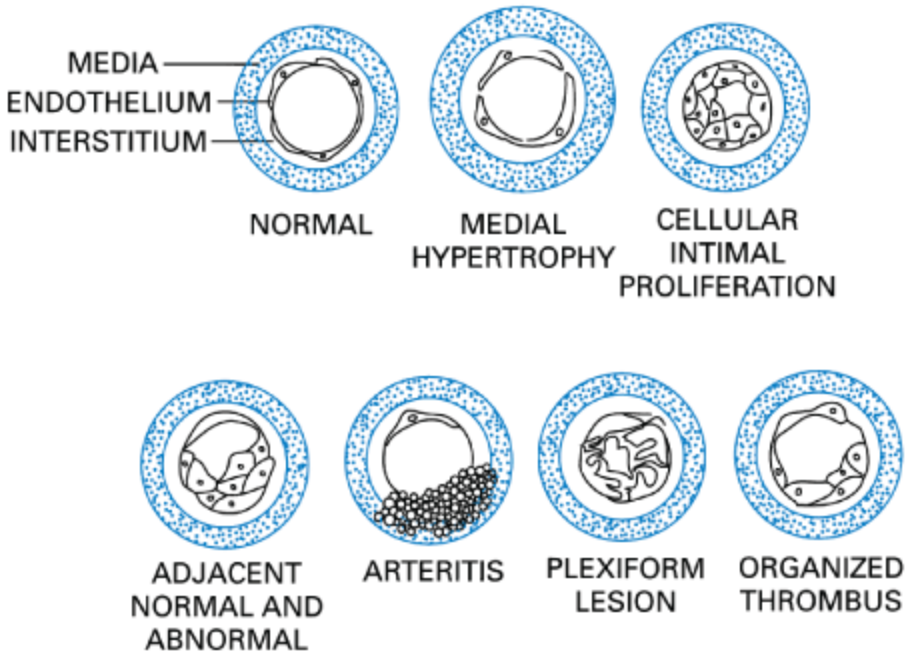
Group 2, PH due to left heart disease: This group demonstrates the following pathological lesions: enlarged, thickened pulmonary veins, interstitial oedema, dilated pulmonary capillaries, alveolar haemorrhage, and lymphatic vessel and lymph node enlargement. Distal pulmonary arteries also show medial hypertrophy and intimal fibrosis.



Potential pathobiological and pathogenetic mechanisms of PAH

Group 3, PH due to lung diseases and/or hypoxia: Intimal proliferation of the small, distal pulmonary arteries and medial hypertrophy are the characteristic pathological changes seen in this group. Also seen are fibrotic areas and variable levels of reduction of the vascular luminal area in the emphysematous lung.

Group 4, CTEPH: Characteristic pathological lesions include organized thrombi adherent to the medial layer of the medium sized pulmonary arteries, which replace the normal intima, occlude the lumen to varying degrees or form webs and bands. A pulmonary arteriopathy identical to that of PAH is seen in the areas not containing the thrombi. Collateral vessels from the systemic circulation sometimes grow to reperfuse the areas downstream to the total obstructions.



Vascular lesions in IPAH

Group 5, PH with multifactorial mechanisms: There are no specific pathological changes that are unique to this group, which includes different conditions with different pathological lesions with unclear or multifactorial causes.

DIAGNOSIS OF PH

The diagnosis of PH is usually made at an advanced stage of the disease. The natural course of the disease is characterized by progressive clinical worsening and reduced life expectancy. Screening for the diagnosis of PH is commonly made by transthoracic echocardiography(TTE), and the final confirmation of the disease is by right heart catheterisation.[24] The diagnostic algorithm of PH involves a battery of tests to make the diagnosis and to place it in the appropriate clinical group and subtype of PH. However, the disease is not easy to diagnose. The predominant and common symptoms of PH are dyspnea and easy fatiguability; as the disease progresses, patients develop palpitations, chest pain, leg edema and ascites; syncope can also occur. A high level of suspicion is necessary diagnose PH. An usual delay of 2 to 3 years from the onset of symptoms to the establishment of the diagnosis of PH is usual.

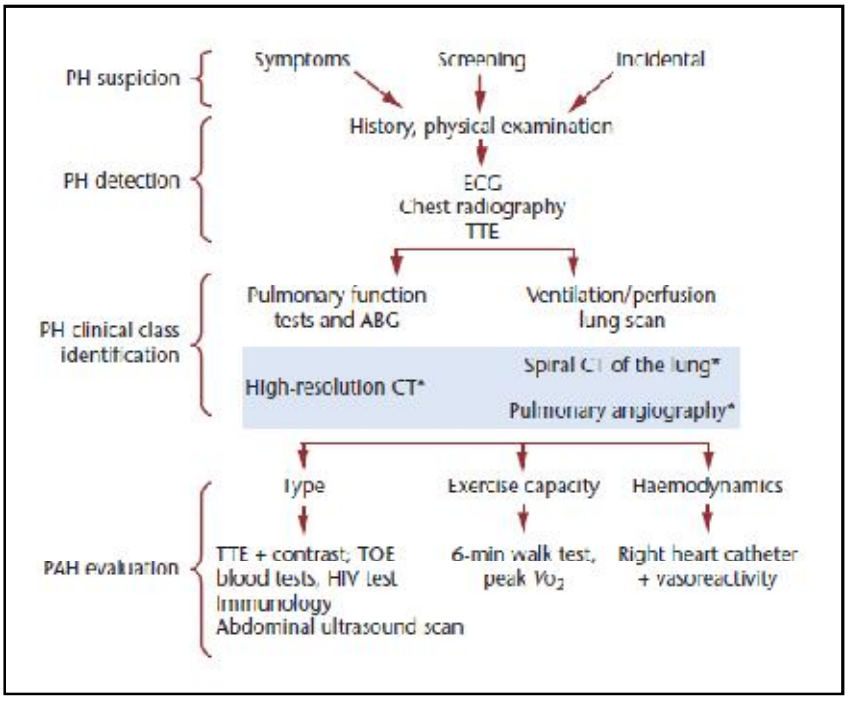
Electrocardiogram

The electrocardiogram (ECG) features seen in cases of PH are: features of right ventricular hypertrophy: right axis deviation, persistent S wave upto V6 and R> S in V1. However, the sensitivity and specificity of the ECG in the diagnosis of PH are very low and so ECG is not a useful screening tool for diagnosing PH. However, there are a few

ECG findings in patients with IPAH that are useful in predicting the prognosis: Over a 6 year follow-up period, the P wave voltage in lead II of > 0.25 mV has been proven to predict a 2.8-fold increase in the risk of mortality.[19]

Echocardiography

Echocardiography is an important screening tool in the diagnosis of PH. Transthoracic echocardiography (TTE) is useful for Doppler analysis. It is also helpful to establish the diagnosis of myocardial, valvular, and congenital causes for PH. Moreover, the RV morphology can be determined. The 2-D echo findings in PH include: RV hypertrophy, enlarged right sided chambers and reduced global RV function as a consequence of chronic RV pressure overload due to increased PVR.



Diagnostic algorithm for pulmonary hypertension. ABG, arterial blood gases; PAH, pulmonary arterial hypertension; PH, pulmonary hypertension; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography; *, required in specific circumstances

In acute pulmonary embolism, the echocardiographic signs, like the McConnell sign (decreased wall motion in the mid RV free wall and normal wall motion of the apex of the RV), the 60/60 sign (pulmonary Artery Acceleration Time [PAAT] < 60 ms and the tricuspid regurgitation peak gradient (TRPG) > 60 mmHg), and the RV overload criteria (at least one of: right-sided cardiac thrombus, systolic flattening of the interventricular septum, RV/LV ratio > 1, RV diastolic dimension in the parasternal view > 30 mm, PAAT < 60 ms or the tricuspid regurgitation peak gradient (TRPG) > 30 mm Hg in the absence of RV hypertrophy), greatly increase the diagnostic utility of echocardiography to suspect the diagnosis.

Echocardiography can both overestimate as well as underestimate the pulmonary pressures. This is mainly due to the overestimation of TRVmax but can also be due to the overestimation of RAP. Older and obese patients can normally have PAPs that are higher than that in younger and normal weighing patients; a higher threshold of PAP must therefore be used in these patients to diagnose PH.

Lung Scans

Ventilation–perfusion scans are of value in the diagnosis and exclusion of pulmonary thromboembolic disease.

Radionuclide Studies

The response of the RV ejection fraction to exercise can be assessed using radionuclide angiography, which is of prognostic value. Scintigraphy using thallium-201 has also been used in detecting hypertrophy of the RV caused by PH.

Lung Biopsy

The sampling of the lung tissue by either open thoracotomy or thoracoscopy is rarely helpful in finding the etiology of the PH. Moreover, the procedure carries a substantial risk in these hemodynamically compromised individuals. And attempts to predict responsiveness to vasodilators based on lung biopsy have had little success.

CT / CT pulmonary angiography

The etiological conditions that can be diagnosed by high resolution CT are: interstitial lung disease, connective tissue disease, CTEPH (mosaic pattern is seen indicating areas of hyperperfusion interspersed with areas of hypoperfusion), PVOD and PCH .

Magnetic resonance (MR) imaging

Assessment RV volumes, mass and function are reliably done using magnetic resonance (MR) imaging. MR angiography may in the future be the diagnostic test of choice in acute pulmonary embolism and CTEPH. MR imaging findings in PH includes: delayed hyperenhancement, changes of septal curvature, RV ejection fraction, and non-invasively measured cardiac index.[25]

Other tests

6 min walking test , pulmonary function test and other laboratory tests including markers of autoimmune diseases like antinuclear antibodies (ANA), markers of coagulation disorders, screening for HIV and viral hepatitis, and (eg, protein S and C, lupus anticoagulants, von Willebrand factor)etc., should be done. Quantification of the

levels of the cardiac biomarker brain natriuretic peptide (BNP, NT-proBNP) is of immense prognostic value and also useful in assessing the therapeutic efficacy of various drugs.

Right heart catheterisation and vasoreactivity testing

Echocardiography has its own limitations in assessment of the pulmonary hemodynamics in patients with PH. For example, echo is not able to predict the transpulmonary blood flow and pulmonary venous pressure reliably. Right heart catheterization(RHC) is the gold standard for establishing the diagnosis of PH and for vasoreactivity testing.[25]

Hemodynamics predict the prognosis in PH. Obtaining the PCWP at rest and after vasodilator challenge is needed for the establishing the etiology of PH. Furthermore, another invaluable parameter derived is the transpulmonary gradient (MPAP - PCWP), which is increased in patients with PAH, but normal in those with PH resulting from left heart disease. An elevated PVR reflects an raised transpulmonary gradient and decreased cardiac output.

Vasoreactivity testing using a short acting vasodilator is useful to assess the acute response of the pulmonary circulation and thus to select patients for high dose calcium channel blocker therapy.

Although the gold standard for the definitive diagnosis of PH is invasively obtained pulmonary pressures got by RHC, precise noninvasive measurement of pulmonary

arterial pressures is indispensible for diagnostic and prognostic purposes and to assess response to therapy.

ROLE OF ECHOCARDIOGRAPHY IN PULMONARY HYPERTENSION

Pulmonary hemodynamics are involved in many clinical situations, because of the close relationship between left-heart and right-heart hemodynamics, and also because the pulmonary vasculature is a target for all the diseases that damage the arteries. The study of pulmonary hemodynamics is of immense importance in many diseases which directly or indirectly involve the cardiopulmonary apparatus. A more accurate evaluation of pulmonary hemodynamics is valuable for the diagnosis and the prognosis of specific clinical diseases and also to validate new therapeutic approaches.

The accurate estimation of PAP and PVR is a major step in the diagnosis, prognosis, the selection of appropriate therapy, and the follow-up of patients with PH. Though the gold-standard method for evaluating pulmonary hemodynamics is unquestionably invasive right-heart study, its use cannot be justified for many conditions.

Ultrasound imaging has continuously evolved over the recent years, leading to the development of several new echocardiographic indices that allow the evaluation of pulmonary pressures (systolic, mean, and diastolic) and also the estimation of other pulmonary hemodynamic parameters, such as PVR, PCWP and the pulmonary capacitance and impedance. Thus, it is now possible to obtain a complete and accurate description of the pulmonary hemodynamics using noninvasive echo imaging[26].

Non-invasive assessment of systolic pulmonary artery pressure is a routine investigation in all the echocardiographic laboratories. Doppler echocardiography is recommended as the initial noninvasive modality of choice in the screening and evaluation of PH. Echocardiography is useful in evaluating the right-sided chamber size and function and also the presence of pericardial effusion, which are known to impact survival in patients with PH. Pericardial effusion, septal displacement(which appears flat or bows towards the right ventricle because of a decreased interventricular pressure gradient when pulmonary pressure becomes near systemic) and right atrial enlargement are the three significant echocardiographic abnormalities that predict adverse outcomes in patients with severe IPAH. These characteristics help identify patients in whom more intensive medical therapy or earlier transplantation are warranted[27].

Many echocardiographic signs can be present in patients with PH, involving the right ventricle (hypertrophy, dilation, or reduction of systolic function). Though Doppler echocardiography has long been used to estimate systolic pulmonary artery pressure, because of its limited accuracy and reproducibility, invasive cardiac catheterization remains the gold standard for the accurate assessment of right heart hemodynamics[28]

REVIEW OF LITERATURE

Many echocardiographic indexes have been proposed over the past few years, to improve, replace, or complete the standard basic echocardiographic evaluation of pulmonary hemodynamics[28].

Doppler echocardiography is helpful in the estimation of the RV systolic pressure. The pressure gradient between the RV and the right atrium is estimated using the modified Bernoulli equation, $PG = 4v^2$, where v is the maximum velocity of the tricuspid regurgitant jet. An estimated right atrial pressure is then added to this value to obtain the right ventricular systolic pressure. This is equal to the pulmonary artery systolic pressure in the absence of pulmonary stenosis. Determination of PASP from the sum of the peak RV-RA gradient and the estimated RA pressure has been proved to be a reliable method since the publication by Yock and Popp[29,30] in 1984 and has also been proven in other studies.[31] Many investigators have repoted a strong correlation between the Doppler estimates of pulmonary artery pressures using this method and the invasively obtained measurements during right-heart catheterization.

The major concern in the noninvasive evaluation of PASP (and of MPAP and PADP)since it is an important screening test, is to reduce false-negative results as much as possible (ie, to minimize error during the estimation of PASP). The underestimation of PASP with echocardiography is mostly due to the underestimation of RAP and of TRvmax. To minimize this error, TRv should be measured in multiple views, looking for the maximal TRvmax; color flow Doppler should be used to get the best alignment

between the regurgitant flow and the Doppler sample volume . Many studies have also shown that inadequate TRvmax signals can be enhanced with the use of contrast [32,33,34,35,36].

Although the application of this technique to estimate PASP has been widely validated, its precision is questionable: in studies that have compared the echocardiographically estimated values with the true values measured by right-heart catheterization, the mean difference ranged from 3 to 38 mm Hg. The PASP was underestimated by the echocardiographic method by >20 mm Hg in 31% of all patients studied[18]. In a more recent study, in 48% of 63 patients studied, echocardiography-derived PASP differed by more than 10 mm Hg from the invasively measured PASP; the magnitude of PASP underestimation was found to be greater than that of its overestimation, particularly at higher PA pressures[37]. The simplified Bernoulli equation may occasionally underestimate the RV-RA gradient because it neglects the inertial component of the complete Bernoulli equation[38]. In patients with severe TR, the Doppler envelope may be cut off because of the early equalization of the RV and RA pressures, and in such situations, the simplified Bernoulli equation may underestimate the RV-RA gradient. TR signal is sometimes not sufficient to perform this measurement, as shown by a recent study that 25% of patients in a randomly selected cohort had insufficient TR for EPASP determination.

For this reason, PASP evaluation with Doppler methods must not be used to decide when to treat patients or to monitor efficacy of therapy [24,25].

Though the accuracy of Doppler PASP measurements has been questioned, thus limiting its utility as a diagnostic tool in asymptomatic PH,[39] PASP estimation by TRvmax measurement remains the most feasible screening method in cases with suspected PH and also in patients with risk factors for the development of PH (family history, connective tissue diseases, HIV infection, portal hypertension, congenital heart diseases and chronic hemolytic anemia, as well as the use of drugs like fenfluramine derivatives, amphetamines, etc.). [16] TRvmax > 2.8 m/s (corresponding to a RA-RV peak pressure gradient > 31 mm Hg) is considered a reasonable cutoff value to define elevated pulmonary artery pressures, except in the elderly and in very obese patients, in whom physiologic PASP tends to be more elevated[40].

The European guidelines for the diagnosis and the treatment of PH consider echocardiographic diagnosis of PH to be ''likely'' when TRvmax is >3.4 m/s (or PASP is >50 mm Hg) and to be ''possible'' when TRvmax is between 2.9 and 3.4 m/s (or PASP is between 37 and 50 mm Hg), with or without other echocardiographic signs suggestive of PH, or when TRvmax is >2.8 m/s (or sPAP is >36 mm Hg) with other findings suggestive of PH (RV hypertrophy or dilatation, increased pulmonary regurgitant velocity [PRv], etc).

Though TTE estimates of PASP are derived from the maximal velocity of the tricuspid regurgitation jet by convention, sometimes, there is insufficient TR to derive the estimated peak systolic pulmonary artery pressure in quite a number of patients.

Though contrast agents can be used to enhance the tricuspid regurgitation signal, this requires venous catheterization.

Other less invasive echocardiographic methods are therefore required to estimate the PASP. To date, in the absence of tricuspid regurgitation, no other noninvasive method of estimating the PASP has been developed.

Alternative TTE methods for pulmonary artery pressure estimation have been evaluated. These include the measurement of blood flow through an anatomic defect (patent ductus arteriosus, ventricular septal defect, or aortopulmonary shunt), measurement of the peak systolic and the end-diastolic pulmonary valve regurgitant velocity, and the measurement of the pulmonary artery acceleration time(PAAT) .

The application of the simplified Bernoulli equation to the end-diastolic PRv is useful in the calculation of the pressure gradient between the right ventricle and the pulmonary artery in end-diastole; this value added to RAP estimates PADP, with a strong correlation with invasive PADP measurements[41] Recently Ristow et al[42] demonstrated that when the end-diastolic pulmonary regurgitant gradient is >5 mmHg ,it predicts cardiac dysfunction, particularly in patients with poor functional status, elevated serum B-type natriuretic peptide, elevated LV mass index, and in those with systolic and diastolic dysfunction. As in cases with tricuspid regurgitation, weak pulmonary regurgitant Doppler signals may be enhanced with the use of contrast.[43,44]

The PRv pattern, when present, is characterized by a rapid rise in the flow velocity immediately after closure of pulmonary valve and a gradual deceleration until the

pulmonary valve opening in the next cardiac cycle (end-diastolic PRv). Masuyama et al[45] showed that the application of the Bernoulli equation to the peak PRv shall provide a reasonable estimate of MPAP. More recently, Abbas et al[46] has also validated this method in another study and showed that adding RAP improves the accuracy of the MPAP estimate.

Aduen et al [47] proposed a new, simple method to estimate MPAP by the addition of the estimated RAP to the RV-RA mean systolic gradient obtained by tracing the TRv profile. This method was validated in 102 patients. It was compared with simultaneous right-heart catheterization derived values; it showed great reliability and accuracy in diagnosing PH. This method appears very simple and also can easily be incorporated into a standard echocardiographic examination protocol, allowing a reliable estimation of MPAP.

RV isovolumic relaxation time (RVIRT) and tissue Doppler–derived RVIRT have also been studied to examine their usefulness in estimating the systolic pulmonary artery pressure (PASP). Brechot et al.[48] had studied 26 patients by echocardiography and cardiac catheterization. Doppler-derived RVIRT correlated strongly with PASP and it was possible to reliably exclude PH. But, prolonged RVIRT is not specific for PH, and RVIRT-derived PASP did not agree well with the invasively-derived value.[49]

An accurate estimation of the RAP is of immense importance to obtain accurate noninvasive evaluations of pulmonary artery pressures. Because RAP is strongly correlated with central venous pressure,[50] the most widely used method for its

estimation is the observation of the diameter and also the collapsibility of the inferior vena cava.[51] The IVC is examined in the subcostal view; the patient should be in supine position, because IVC size is significantly smaller in the left lateral position and significantly larger in the right lateral position.[52] IVC diameter is measured within 2 cm of the RA – IVC junction at end-expiration and end-diastole[53] and during a ‘‘sniff’’ maneuver; the decrease of its diameter with the sniff maneuver is a measure of IVC collapsibility.[51] The IVC can be dilated (>2 cm) in younger patients despite normal RAPs[52,54]; IVC size is also considered with caution in patients who are on mechanical ventilation.

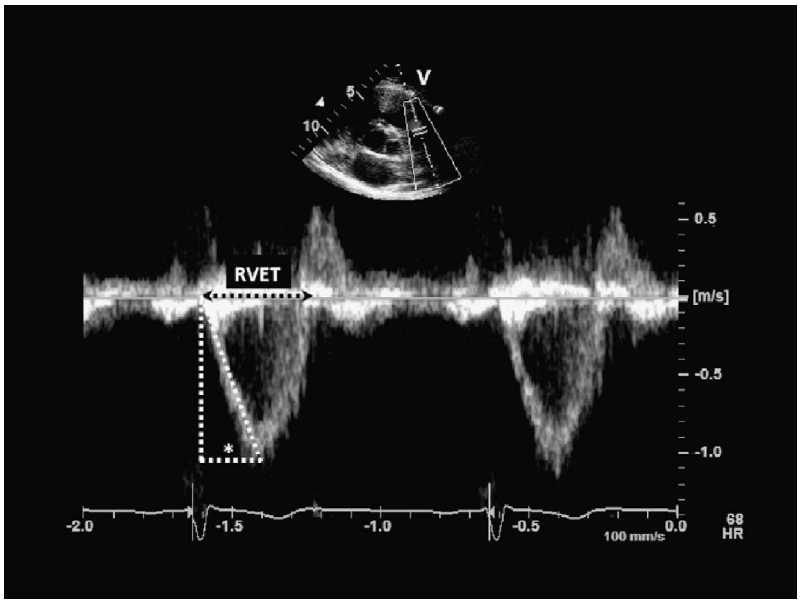
Under normal conditions, the Doppler pulmonary flow velocity curve has a domelike contour; the maximum velocity is in the middle of systole. In PH, it is more triangular in contour; the peak velocity is in early systole; in some cases a slower rise during deceleration can also be observed, resulting in mid systolic notching.

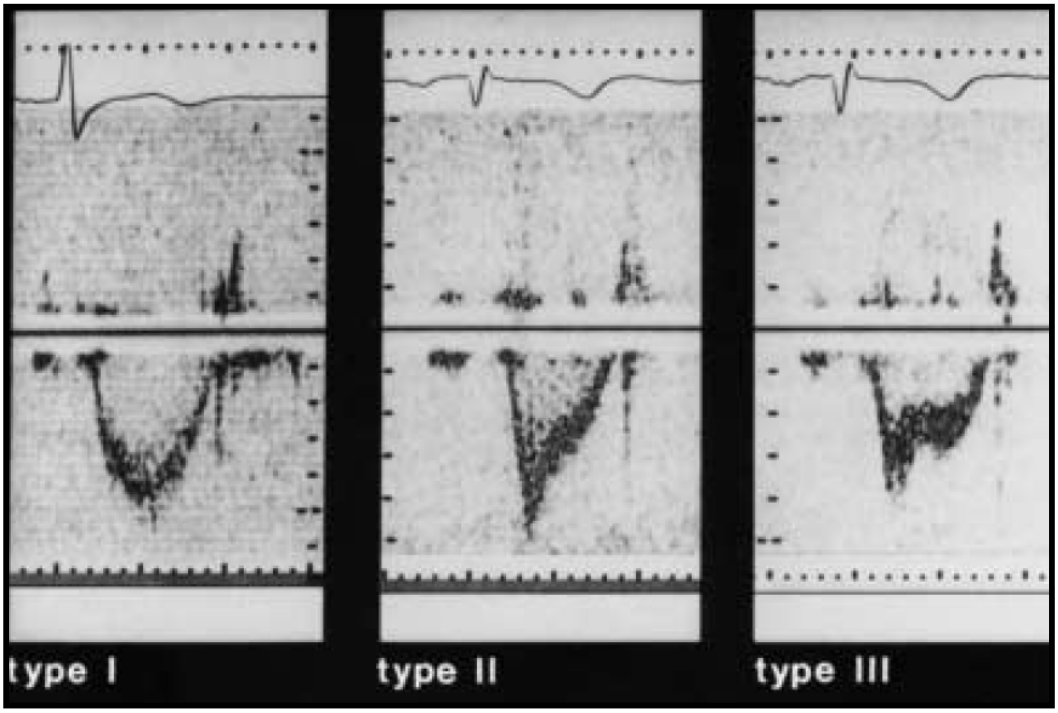
PH in humans is thus characterized by a shortening of the pulmonary artery acceleration time (PAAT) as measured by Doppler echocardiography; as the pulmonary artery pressure increases, the pulmonary acceleration time shortens. Increase in heart rate is also known to reduce the PAAT. It has been demonstrated that increase in heart rate shortens pulmonary artery acceleration time only at lower MPAP, but have little effect on PAAT at higher (> 25 mm Hg)MPAP[55].

The pulmonary artery acceleration time (PAAT), is defined as the time interval from the onset of forward flow in the pulmonary artery to the peak velocity of this flow;

this has been shown to be inversely related to PASP and MPAP. In a study by Lanzarini et al,[56] a PAAT< 93 ms identified 67.4% of patients with PH. In combination with other indexes of pulmonary

Pulsed-wave Doppler interrogation of the pulmonary artery. RVET is measured from the onset of RV ejection to that of zero flow. PAAT is the interval from the onset of RV ejection to peak flow velocity (asterisk).





Doppler pulmonary flow velocity curves in a patient without pulmonary hypertension (Type I) and in two patients with pulmonary hypertension (Types II and III). Type I: normal, dome-like contour with a maximum velocity in the middle of systole. Type II: triangular contour, with a sharp peak in early systole, and a decreased acceleration time. Type III: similar to Type II, but with a mid-systolic notching.

pressures, PAAT can be a very powerful tool in the diagnosis of PH.

THE MPAP may be estimated by using PAAT measured by pulsed Doppler of the pulmonary artery in systole; MPAP = 79 - (0.45x PAAT). In patients with PAATs < 120 ms, the formula for MPAP is 90 - (0.62 x PAAT) performs better. Generally, the shorter the AT, the higher the PVR and hence the PA pressure, when the heart rate is in the normal range of 60 to 100 beats/mins.[30,57]

In 1983 , Kitabatake *et al.* [20] studied a series of 33 patients, of whom 16 had a MPAP higher than 20 mmHg by Doppler echocardiography. In the patients with a normal *PAP*, ejection flow velocity reached peak at mid-systole, producing a dome-like

contour; in the patients with PH, the time to peak flow velocity (PAAT) reduced, producing a triangular contour. In 10 patients, a slower secondary rise was observed during deceleration , resulting in mid-systolic notching . Satisfactory Doppler recordings could be obtained in 70% of patients examined in the catheterization laboratory. This increased to 90% in patients with PH. The study also showed a significant correlation between pulmonary valve motion and the pulmonary artery flow velocity pattern; but it was noted that mid-systolic notching is not always related to the severity of PH, and can be intermittent.

Kitabatake et al.[58] showed that PAAT correlates well with MPAP and its logarithm as determined by cardiac catheterization. They further showed that PAAT corrected for RVET time, a method of adjusting for heart rate, slightly strengthened the correlation between PAAT and MPAP. In a subsequent study, Dabestani et al. described the same relationship as one that observed the following equation: MPAP = 73 - (0.42 x PAAT). In contrast to Kitabatake et al., they found that neither the logarithmic transformation of MPAP nor the correction for RVET improved the accuracy of estimating the MPAP using PAAT. Together, these studies established the capacity of Doppler derived measurements of PAAT to provide accurate estimates of MPAP. In addition, PAAT in the RV outflow tract, unlike estimates using tricuspid regurgitation velocity, is available in virtually all patients.[58]

Pulmonary artery acceleration time measurement, previously thus shown to correlate well with invasively measured MPAP, is an useful alternative to the tricuspid

regurgitation Vmax-dependent method; it does not rely on the presence of an anatomic defect or valvular regurgitation; it is measurable in most of the individuals. Currently, measurement of PAAT cannot be used as an alternative to TRVmax for the derivation of EPASP, because the relationship between these two parameters has not been validated.

Despite many important publications, the use of PAAT in clinical practice has so far remained relatively limited. This is because the majority of the publications reporting echocardiographic PAP estimates have relied on TR Vmax-derived EPASP.

Most clinicians who rely on TTE for PAP quantification have developed a familiarity with and a preference for peak systolic, and not the mean, pulmonary artery pressure values. Despite the well-established role of invasively measured MPAP values in the diagnosis and management of PH, the use of noninvasively derived EPASP values is also justifiable, given their accuracy, reproducibility, and extensive validation.[18]

The relationship between different components of pulmonary artery pressure (SPAP, MPAP, and PADP) has been shown to remain constant after changes in posture and activity,[59] which implies that any of the three can be used as a surrogate of the other two. Accurate and precise estimates of MPAP may be obtained by using PASP. The single-pressure model formula, mPAP = 0.61 × PASP + 2 mm Hg, was most accurate, in a recent study by Chemla et al.[60]

Although many useful methods of assessing MPAP have been developed, there currently exists no method that can be used to derive an EPASP value in the absence of TR. In a recent series, a significant number of patients with pulmonary artery pressures

>50 mm Hg had mild TR or less, rendering the reliance on TRVmax for the measurement of EPASP unfeasible.[61] Although saline injection is useful to augment a weak or immeasurable TRsignal,[62]. this approach involves the insertion of an intravenous line and coordinated injection of agitated saline and simultaneous color Doppler interrogation of the tricuspid valve. Although this technique may be useful, it is resource and time consuming and thus may not be optimal in a busy echocardiography laboratory. This underscores the need for a method to pulmonary artery pressure assessment that is not dependent on the presence of TR and thus justifies the use of a PAAT derived method in the echocardiography laboratory.

Yared et al[63] observed a strong, inverse correlation between PAAT and EPASP among a cohort of patients with a wide range of EPASP values. Quantification of this relationship by linear regression led to the derivation of an equation by which PAAT could be used to provide EPASP values comparable with those obtained by using TRVmax.

This TR-independent approach using PAAT for the quantitative assessment of EPASP performed well across a wide range of pulmonary artery pressures. The use of PAAT thus, for the derivation of EPASP increases the overall percentage of patients in whom noninvasive assessment of pulmonary hemodynamics can be performed. PAAT was found to be easily obtainable and also strongly correlated with TRVmax.

However, an important limitation of this study was that it was a comparison of measurements derived from only the echocardiograms of patients, without correlative

invasive hemodynamic measurements, which is the gold standard. Confirmation of the findings using invasive measurement of peak systolic pressure is important.

In our study, we aimed to overcome this limitation and to correlate the PASP and the MPAP obtained by invasive right heart pressure study, with the measurements obtained non invasively by Doppler echocardiography derived PAAT and also the EPASP derived from TRVmax. We examined the relationship between pulmonary artery acceleration time and both tricuspid regurgitation Vmax and estimated peak systolic and mean pulmonary artery pressure. We also evaluated the accuracy of Doppler echocardiography in estimating pulmonary artery systolic and mean pressures, by measuring pulmonary artery acceleration time and tricuspid regurgitation Vmax, and comparing it with invasively determined right heart pressures in patients referred to our department for evaluation or treatment of pulmonary hypertension , in whom right heart catheterization for pressure study was clinically indicated. Doppler echocardiography was performed within one hour of hemodynamic assessment by right-heart catheterization.

AIM OF THE STUDY

The aim of the study was

1. To estimate the pulmonary artery systolic pressure by measuring the tricuspid regurgitation peak gradient by Doppler echocardiography in patients with pulmonary hypertension and compare it with invasively derived pulmonary artery systolic pressure obtained by right heart catheterization.
2. To estimate the mean pulmonary artery pressure from pulmonary artery acceleration time measured by Doppler echocardiography in patients with pulmonary hypertension and compare it with invasively derived mean pulmonary artery pressure obtained by right heart catheterization.
3. To find which of the above two methods is more accurate in deriving the pulmonary artery pressures.
4. To test the hypothesis that the pulse Doppler echo derived pulmonary artery acceleration time strongly correlates with invasive pulmonary artery systolic pressure.
5. To compare the strength of correlation between pulmonary artery acceleration time and
    a. invasive pulmonary artery systolic pressure
    b. invasive mean pulmonary artery pressure
6. To compare the strength of correlation between invasively derived pulmonary artery systolic pressure and
    a. TRPG derived EPASP
    b. PAAT

MATERIALS & METHODS

Study Population:

The study was conducted in patients referred to the Department of Cardiology, Govt. Rajaji hospital, Madurai for cardiac evaluation, in whom pulmonary hypertension was diagnosed based on transthoracic echocardiography and right heart catheterization was clinically indicated. Fifty three patients, twenty males and thirty three females, with a diagnosis of pulmonary hypertension established by transthoracic echocardiography, in whom right heart catheterization was clinically indicated were studied. The clinical indication for catheterization was primary pulmonary hypertension in 5 patients, mitral valve disease in 19, congenital heart disease with shunt lesion in 19, chronic pulmonary thrombo embolic pulmonary hypertension in 3, connective tissue disorder in 4, lung disease in 2 and other conditions in 1. Forty patients had clinical evidence of pulmonary hypertension, 8 had clinical tricuspid regurgitation and none had clinical pulmonary regurgitation. Fifty patients were in sinus rhythm and three in atrial fibrillation.

Inclusion Criteria:

Patients with pulmonary hypertension of various etiologies were included in the study.

Exclusion Criteria:

1. Paediatric age group patients were excluded
2. Patients undergoing simultaneous left heart catheterization were not included.
3. Patients with poor echo window were not included.

4. Critically ill patients were also excluded.

The instituitional ethical committee approval was obtained and all the patients selected for the study gave informed consent to undergo evaluation.

Methods

All the patients included in the study were subjected to detailed history taking and thorough and complete physical examination. Complete blood count, blood sugar and renal function test were done in all patients. A 12 lead electrocardiogram and a chest X-ray were obtained in all patients. They were also evaluated for the etiology of pulmonary hypertension by appropriate tests as indicated: anti nuclear antibody profile, coagulation profile, HIV testing, high resolution CT scan of the chest, ultrasound abdomen and pulmonary function testing.

Echocardiographic evaluation

All the patients underwent a detailed transthoracic echocardiographic evaluation using a standard protocol, within one hour of undergoing the right heart catheterization study. Two dimensional, M-mode , colour flow, spectral Doppler and tissue Doppler examinations were done using Philips IE-33 echocardiography machine. ECG monitoring was done during the examination. Examination was done in the left lateral decubitus and in the supine positions.

To assess RV size, function and area, a complete set of standardized views were obtained. These included PLAX, parasternal RV inflow, PSAX, apical 4-chamber, right ventricle–focused apical 4-chamber , and subcostal views.

The basal diameter, defined as the maximal short-axis dimension in the basal one third of the right ventricle was measured on the RV focused apical 4-chamber view.

Measurement of right ventricular outflow tract (RVOT) dimensions were made at the proximal or subvalvular level (RVOT-Prox) and at the distal or pulmonic valve (RVOT-Distal) levels in the parasternal long-axis RVOT anterior portion view, basal parasternal short-axis view, and parasternal short-axis of pulmonary bifurcation view.

Measurement of end-diastolic right ventricular wall thickness was made in the subcostal 4 chamber view.

RVSP and therefore the EPASP was determined from the peak TR jet velocity, using the simplified Bernoulli equation and this value was combined with an estimate of the RA pressure: EPASP = $4(V)^2$ + RA pressure, where V is the peak velocity (in meters per second) of the tricuspid valve regurgitant jet . TR signals were obtained from several windows and the signal with the highest velocity was used. Doppler sweep speed of 100 mm/s was used for all tracings.

RA pressure was estimated by IVC diameter and the presence of inspiratory collapse. The subcostal view was used for imaging the IVC, with the IVC viewed in its long axis. The measurement of the IVC diameter was made at end-expiration and just proximal to the junction of the hepatic veins with the IVC. To assess IVC collapse, the change in diameter of the IVC with sniff and also with quiet respiration were measured, ensuring that the change in diameter did not reflect a translation of the IVC into another plane.

Table 4: Estimation of RA pressure on the basis of IVC diameter and collapse

Variable	Normal (0-5 [3] mm Hg)	Intermediate (5-10 [8] mm Hg)		High (15 mm Hg)
IVC diameter	≤ 2.1 cm	≤ 2.1 cm	≥2.1 cm	≥2.1 cm
Collapse with sniff	> 50%	< 50%	>50%	<50%

PADP was estimated from the velocity of the end-diastolic pulmonary regurgitant jet using the modified Bernoulli equation: [PADP = 4 x (end-diastolic pulmonary regurgitant velocity)^2 + RA pressure].

Pulsed-wave and continuous-wave Doppler interrogation of the proximal pulmonary artery was performed in the parasternal short-axis view with the sample volume placed along the long axis of the main pulmonary artery to maximally align blood flow and Doppler interrogation. This view was also used to exclude pulmonary stenosis. Using the pulse-wave Doppler profile, PAAT, RVET, and heart rate were measured. PAAT was defined as the interval between the onset of systolic pulmonary arterial flow and peak flow velocity . RVET was defined as the interval between the onset of RV ejection to the point of systolic pulmonary arterial flow cessation. All values used for the analysis were the average of three consecutive cardiac cycles, but in patients with atrial fibrillation, five-beat averages were obtained. Mean PA pressure was estimated from PAAT measured by pulsed Doppler of the pulmonary artery in systole: Mean PA pressure = 90 - (0.62 x AT) {Mahn & Dabestani formula}.

Table 5: Abnormal Values	
RV basal diameter cm	>4.2
RV subcostal wall thickness mm	>5
RVOT PSAX distal diameter cm	>2.7
RVOT PLAX proximal diameter cm	>3.3
TAPSE cm	<1.6
Pulsed Doppler peak velocity at the annulus(Tric s')cm/s	<10
FAC (%)	<35
E/A ratio	<0.8 or >2.1
E/e'ratio	>6
Deceleration time ms	<120

The percentage RV fractional area change, FAC, which is a measure of RV systolic function, and defined as (end-diastolic area - end-systolic area)/end-diastolic area x 100 was obtained by tracing the RV endocardium both in systole and diastole from the annulus, along the free wall to the apex, and then back to the annulus, along the interventricular septum.

Tricuspid annular plane systolic excursion (TAPSE) was acquired by placing an M-mode cursor through the tricuspid annulus and measuring the amount of longitudinal motion of the annulus at peak systole in the apical 4 chamber view.

RV s' or systolic excursion velocity was measured in the apical 4-chamber window, with a tissue Doppler mode region of interest highlighting the RV free wall. The pulsed Doppler sample volume was placed in either the tricuspid annulus or the middle of the basal segment of the RV free wall. The velocity RV s' was measured as the highest systolic velocity, without over-gaining the Doppler envelope.

The parameters used to assess RV diastolic function namely, the Doppler velocities of the transtricuspid flow (E, A, and E/A), tissue Doppler velocities of the tricuspid annulus (e', a', E/e') and the E- deceleration time were measured in the apical 4 chamber view.

GRADING OF RV DIASTOLIC DYSFUNCTION. : A tricuspid E/A ratio < 0.8 impies impaired relaxation, a tricuspid E/A ratio of 0.8 to 2.1 with an E/e' ratio > 6 impies pseudonormal filling, and a tricuspid E/A ratio > 2.1 with deceleration time < 120 ms implies restrictive filling.

Right heart Catheterisation

Right heart catheterization was performed after overnight fasting, at rest in the cardiac catheterization laboratory using the TOSHIBA machine, without sedation by the standard technique. Catheterisation was done under local anaesthesia, through the right femoral venous route. Multipurpose catheter was used for pressure measurements. Pressure measurements were taken from the pulmonary arterial wedge position, main pulmonary artery , right ventricle and right atrium at the end of expiration.

Statistical Tools

The information collected regarding all the selected cases were recorded in a Master Chart. Data analysis was done with the help of computer using **Epidemiological Information Package (EPI 2010)** developed by Centre for Disease Control, Atlanta.

Using this software range, frequencies, percentages, means, standard deviations, chi square and 'p' values were calculated. Kruskul Wallis chi-square test was used to test the significance of difference between quantitative variables and Yate's chi square test for qualitative variables. A 'p' value less than 0.05 is taken to denote significant relationship. Correlation coefficients were calculated using Excel software.

RESULTS

Among this study population, pulsed-wave Doppler imaging of the main pulmonary artery was sufficient to measure PAAT in all the patients (53 of 53) studied. In contrast, 9.4% (5 of 53) did not have sufficient TR to measure TRVmax and only 43.4% of patients(23 of 53) had sufficient PR to measure PR end diastolic velocity.

Totally, 53 patients were included in the study. Of this , 20 (37.7%) were males and 33(62.3%) were females. The mean age of the patients was 33.7 ± 14.7 years. The age distribution of the patients studied was as in Table 1. Paediatric age group was not included in the study.

Table 6: Age distribution

Age group	Cases	
	No	%
Below 20 years	11	20.8
20-29 years	13	24.5
30-39 years	10	18.9
40-49 years	11	20.8
50 years & above	8	15.1
Total	53	100
Range	13 - 65 years	
Mean ± SD	33.7 ± 14.7 years	

Table 7: Symptoms

Symptoms	Yes		No	
	No	%	No	%
Chest pain	19	35.8	34	64.2
Shortness of breath	47	88.7	6	11.3
RV failure symptoms	2	3.8	51	96.2

The most common presenting symptom was shortness of breath, which was present in 47(88.7%) of the patients studied. Symptoms of right ventricular failure was present only in two (3.8%) of the patients studied. Seven(35%) of the males and none of the females studied were smokers. The pulse rate of the patients studied ranged from 64 to 112 beats per minute, with a mean of 82.3± 12.6.

Table 8: ECG Findings

ECG results	Cases	
	No.	%
AF	3	5.7
RVH	19	35.8
RBBB	9	17.0
BVH	3	5.7

Two of the 53 patients studied were in atrial fibrillation and the rest were in sinus rhythm. ECG evidence of right ventricular hypertrophy was present in 19(35.8%) of the patients studied; RBBB was present in 9 (17.0%) patients, all of them with large ASD with pulmonary hypertension.

Table 9: Groups of PH

Group	Clinical Diagnosis	Cases	
		No.	%
1	CHD	19	35.8
	Cor AVF	1	1.9
	PPH	5	9.4
	SScl	4	7.5
2	RHD	19	35.8
3	Cystic lung	1	1.9
	ILD	1	1.9
4	CPTE	3	5.7
All	Total	53	100.0

54% (29 of 53) of our patients belonged to group 1 pulmonary hypertension. Of them, 35.8%(19 of 53) had shunt lesion as the cause of PAH, 1 patient due to a coronary AV fistula, 7.5%(4 of 53) had systemic sclerosis and 9.4% (5 of 53) had idiopathic PAH. Group 2 PH due to left heart disease was present in 35.8% (19 of 53). Group 3 PH due to lung disease was present in 3.8%(2 0f 53) and group 4 due to (3 of 53).

Table 10 :TTE derived Pulmonary Hemodynamics

Parameter	Range	Mean ± S.D.
Tricuspid regurgitation Peak gradient	32 – 101	66.2 ± 23.2
Estimated Right Atrial Pressure	3 – 15	5.36 ± 1.64
Estimated Systolic Pulmonary Artery Pressure	37 – 106	71.7 ± 23.9
Pulmonary Artery Acceleration Time	57 – 101	76.8 ± 13.8
Right Ventricle Ejection time	239 – 295	267 ± 19.4
PAAT / RVET ratio	0.2 – 0.41	0.29 ± 0.07
PR derived PA Diastolic Pressure	10 – 37	24.8 ± 8.1
Estimated mean Pulmonary Artery Pressure	27.8 – 54.6	42.6 ± 8.6

The mean value of the tricuspid regurgitation peak gradient(TRPG) was 66.2 ± 23.2 and that of the estimated Systolic Pulmonary Artery Pressure(ESPAP) was 71.7 ± 23.9 Thus most of our patients had severe PH.

The mean Pulmonary Artery Acceleration Time was 76.8 ± 13.8 and the calculated mean pulmonary artery pressure was 42.6 ± 8.6

Table 11: Right Ventricle Dimensions

Right Ventricle Diameter	Range	Mean ± S.D.
Basal (cm)	2.1 – 4.3	3.52 ± 0.41
RV outflow Tract – Proximal (cm)	2.3 – 4.1	3.09 ± 0.5
RV outflow Tract – Distal (cm)	2 – 4	2.79 ± 0.48
RV free wall thickness (mm)	5 - 9	6.5 ± 1.0

The mean basal RV diameter was 3.52 ± 0.41 (Normal <4.2cm). The mean proximal RVOT diameter in PLAX view was 3.09 ± 0.5 (Normal <3.3cm). The mean distal RVOT diameter in PSAX view was 2.79 ± 0.48 (Normal <2.7cm) and the mean RV free wall thickness in subcostal view was 6.5 ± 1.0 (normal <5mm). Only the mean RVOT distal diameter was found to be above normal.

Table 12: RV dimensions: Normal and abnormal

Parameter(abnormal)	Normal		Abnormal	
	No.	%	No.	%
RV basal diameter cm (>4.2cm)	52	98.1	1	1.9
RV free wall thickness (>5mm)	5	9.4	48	90.6
RVOT PSAX distal diameter (>2.7 cm)	22	41.5	31	58.5
RVOT PLAX proximal diameter (>3.3 cm)	35	66	18	34

Table 13: Right Ventricular Systolic Function

Parameter	Range	Mean± S.D.	Cases			
			Normal		Abnormal	
			No.	%	No.	%
Tricuspid annular plane systolic excursion(TAPSE) Normal – 1.6 to 3.0	0.9 – 3.0	2.1±0.59	44	83.0	9	17.0
Tricuspid annular Tissue Doppler velocity(Tric s') Normal – 10 to 19	6.1 – 20	13.47±3.17	49	92.5	4	7.5
Fractional area change Normal > 35%	22 - 60	46.2 ± 9.9	45	84.9	8	15.1

The RV systolic function as measured by TAPSE was normal in 83% (44 of 53) of the patients. Tricuspid s' was normal in 92.5% (49 0f 53) of the patients. The RV fractional area change was normal in 84.9% (45 of 53) of the patients. Overall, 17% (9 of 53) of the patients had RV systolic dysfunction.

Table 14: Right Ventricular Diastolic Function

Diastolic Function	Cases	
	No.	%
Normal	17	32.1
Impaired relaxation	9	17.0
Pseudo normal filling	27	50.9

The RV diastolic function was normal in 32.1% (17 of 53) patients. Impaired relaxation was present in 17% (9 of 53) patients. 50.9 % (27 of 53) patients had pseudonormal filling pattern and restrictive filling pattern was present in none of the patients studied.

Table 15: Invasively obtained Right heart Pressures

Invasive Pressures	Range	Mean ± S.D.
PC Wedge Pressure	8 – 32	14.0 ± 7.33
P.A. Systolic Pressure	38 – 108	70.0 ± 21.54
P.A.Diastolic Pressure	17 – 43	27.96 ± 7.49
Mean Pulmonary Artery Pressure	28 – 58	42.34 ± 8.86
RV Systolic Pressure	40 – 104	71.1 ± 21.4
RV end Diastolic Pressure	3 – 15	9.42 ± 2.53
Right Atrial Pressure	4 - 18	8.81 ± 2.52

The mean value of the PASP measured by right heart catheterization was 70.0 ± 21.54 (Vs the echo – Doppler estimated PASP of 71.7 ± 23.9) in the study population , that of PADP was 27.96 ± 7.49 (Vs echo derived mean value of 24.8 ± 8.1) and the mean pulmonary artery pressure was 42.34 ± 8.86(Vs the echo PAAT derived mean value of 42.6 ± 8.6). The mean right atrial pressure measured invasively had a mean value of 8.81 ± 2.52(Vs echo derived value of 5.36 ± 1.64).

Table16: Classification according to severity of PH

Severity of PH (PASP mm Hg)	Cases	
	No.	%
Mild (38 to 50)	15	28.3
Moderate (50 to 75)	20	37.7
Severe(> 75)	18	34

The pulmonary hypertension was mild in 28.3%, moderate in 37.7% and severe in 34% f the cases.

Correlation between Echo derived findings and Invasively derived findings

There was strong inverse correlation between the echo measured PAAT and both the invasively measured PASP and the MPAP. This correlation was stronger for MPAP. This strong inverse correlation remained thus even after correction for heart rate (i-e) between PAAT/RVET and the invasively measured PASP and the MPAP. This correlation was comparable to that between echo TRVmax derived EPASP and invasively measured PASP. Our study also showed strong direct correlation between echo derived PADP and the invasively measured PADP.

Table 17: Correlation between Echo derived findings and Invasively derived findings

Correlation between	Mean ±SD	Correlation Coefficient	Correlation
Echo derived PAAT	76.8 ± 13.8		
Invasive PSAP	70.0 ± 21.54	**-0.89**	Strong inverse Correlation
Echo derived PAAT	76.8 ± 13.8		
Invasive MPAP	42.34 ± 8.86	**-0.93**	Strong inverse Correlation
Echo derived PAAT/RVET	0.29 ± 0.07		
Invasive PSAP	70.0 ± 21.54	**-0.89**	Strong inverse Correlation
Echo derived PAAT/RVET	0.29 ± 0.07		
Invasive MPAP	42.34 ± 8.86	**-0.90**	Strong inverse Correlation
Echo TRVmax derived ESPAP	71.7 ± 23.9		
Invasive PSAP	70.0 ± 21.54	**0.95**	Strong direct Correlation
Echo derived PADP	24.8 ± 8.1		
Invasive PADP	27.96 ± 7.49	**0.94**	Strong direct Correlation

The numbers marked in bold show positive correlation(>+ 0.5 or < - 0.5)

Table 18: Correlation between Echo derived findings and Invasively obtained findings in different groups of PH

Correlated parameters	Group 1 PAH	Group 2 Left heart disease	Group 4 CTEPH
Echo based PAAT & Invasive PSAP	**-0.85**	**-0.86**	**-1.0**
Echo based PAAT & Invasive MPAP	**-0.86**	**-0.98**	**-1.0**
Echo based PAAT/RVET & Invasive PSAP	**-0.84**	**-0.85**	**-1.0**
Echo based PAAT/RVET & Invasive MPAP	**-0.83**	**-0.94**	**-1.0**
Echo based ESPAP & Invasive PSAP	**0.95**	**0.92**	**1.0**
Echo based PREDP & Invasive PADP	**0.95**	**0.65**	**-**

The numbers marked in bold show positive correlation(>+ 0.5 or < - 0.5)

The strength of correlation between PAAT and PASP and between PAAT and MPAP was strong among the different groups of PH, and this was also not affected by correction for heart rate and was comparable to the strength of correlation between EPASP and invasively measured PASP.

Table19 : Correlation between Echo derived findings and Invasively obtained findings in different degrees of PH

Correlation between	**Correlation Coefficient**		
	Mild PH	**Moderate PH**	**Severe PH**
Echo based PAAT & Invasive PASP	**-0.81**	**-0.78**	-0.09
Echo based PAAT & Invasive MPAP	**-0.90**	**-0.91**	**-0.67**
Echo based PAAT/RVET & Invasive PASP	**-0.79**	**-0.83**	-0.10
Echo based PAAT/RVET & Invasive MPAP	**-0.84**	**-0.78**	**-0.50**
Echo based ESPAP & Invasive PASP	0.40	**0.77**	**0.54**
Echo based PADP & Invasive PADP	0.46	**0.93**	**0.93**

The numbers marked in bold show positive correlation(>+ 0.5 or < - 0.5)

The analysis of results revealed that

1. The correlation between PAAT and PASP was significant only in mild and moderate degrees of PH while it was not so in severe PH.
2. There was significant correlation between PAAT and MPAP in all degrees of PH.
3. Correction for heart rate did not affect the above results.
4. In contrast, correlation between TRVmax derived EPASP and PASP was significant in moderate and severe PH, while it was not so in mild PH.
5. Correlation between PR derived PADP and invasively obtained PADP was also significant in moderate and severe PH, but not so in mild PH.

Table 20: Correlation between Echo derived findings and Invasively obtained findings in different types of RV diastolic function

Correlation between	Correlation Coefficient		
	Normal	**Impaired relaxation**	**Pseudo normal filling**
Echo based PAAT & Invasive PSAP	**-0.86**	**-0.94**	**-0.90**
Echo based PAAT & Invasive MPAP	**-0.89**	**-0.97**	**-0.95**
Echo based PAAT/RVET & Invasive PSAP	**-0.86**	**-0.96**	**-0.91**
Echo based PAAT/RVET & Invasive MPAP	**-0.88**	**-0.87**	**-0.92**
Echo based ESPAP & Invasive PSAP	**0.98**	**0.83**	**0.96**
Echo based PREDP & Invasive PDAP	**0.99**	**1.0**	**0.92**

The numbers marked in bold show positive correlation(>+ 0.5 or < - 0.5)

The strength of correlation between PAAT and PASP and between PAAT and MPAP was strong among the different groups with normal diastolic function, impaired relaxation and pseudonormal filling and this was not affected by correction for heart rate and was comparable to the strength of correlation between EPASP and invasively measured PASP.

Table 21: Correlation between Echo derived findings and Invasively obtained findings in in normal and abnormal RV systolic function

Correlation between	Correlation Coefficient	
	Normal systolic function	**Systolic dysfunction**
Echo based PAAT & Invasive PSAP	**-0.90**	**-0.89**
Echo based PAAT & Invasive MPAP	**-0.95**	**-0.73**
Echo based PAAT/RVET & Invasive PSAP	**-0.90**	**-0.90**
Echo based PAAT/RVET & Invasive MPAP	**-0.93**	**-0.64**
Echo based ESPAP & Invasive PSAP	**0.95**	**0.91**
Echo based PREDP & Invasive PDAP	**0.96**	**0.93**

The numbers marked in bold show positive correlation(>+ 0.5 or < - 0.5)

The strength of correlation between PAAT and PASP and between PAAT and MPAP remained strong after excluding patients with RV systolic dysfunction and also was not affected by correction for heart rate and remained comparable to the strength of correlation between EPASP and invasively measured PASP. The small(9 of 53) group of patients with RV systolic dysfunction also showed a slightly weaker, yet significant correlation among the various above mentioned parameters analysed.

DISCUSSION

TTE has been proved to be an important method in the noninvasive assessment of pulmonary artery pressures in a wide range of diseases.[30,31,45,48,56,57,58] The most widely accepted and employed transthoracic echocardiographic method for the derivation of pulmonary artery pressures relies on measurement of TRVmax. Oftentimes, TR is not sufficient to perform this measurement, as shown by the fact that 9.4% of patients in our study of patients with PH of varied etiologies had insufficient TR for EPASP estimation. Many other techniques had been proposed to assess the pulmonary hemodynamics.

Kitabatake et al.[58] showed that PAAT correlates strongly with MPAP and its logarithm (r = 0.82 and 0.88, respectively) as measured by cardiac catheterization. They also showed that PAAT corrected for RVET, a method of adjusting for the heart rate, slightly strengthened the correlation between PAAT and MPAP.

In a study that followed, Dabestani et al.[57] described the same relationship and derived the following equation: MPAP = 73 - (0.42 x PAAT). In contrast to Kitabatake et al., they showed that both the logarithmic transformation of MPAP and the correction for RVET did not improve the accuracy of estimating the MPAP using PAAT. Together, these two studies established the usefulness of Doppler derived measurements of pulmonary arterial forward flow in providing an accurate estimate of MPAP.

RV isovolumic relaxation time (RVIRT) and the tissue Doppler-derived RVIRT[48] have also been examined in previous studies to determine their usefulness in estimating

the systolic pulmonary artery pressure. Brechot et al.[48] had studied 26 patients by trans thoracic echocardiography and right heart catheterization. Tissue Doppler-derived RVIRT correlated strongly with PASP and was able to exclude reliably the diagnosis of pulmonary arterial hypertension. But, prolonged RVIRT was not specific for pulmonary hypertension. RVIRT-derived PASP also did not correlate with the catheter-based values.

Despite the above important publications, the use of PAAT in clinical practice had so far remained relatively limited. This is mainly because the vast majority of the publications reporting echocardiographic pulmonary artery pressure estimates had relied on TRVmax-derived EPASP. As such, physicians who rely on TTE for pulmonary artery pressure measurement have developed a familiarity with and also a preference for peak systolic, and not mean, pulmonary artery pressure values.

Despite the well-known and established role of invasively measured MPAP values in the diagnosis and management of PH, TRVmax derived EPASP is used more often than PAAT derived MPAP. This inspite of the fact that in a recent series of studies, a significant number of patients with systolic pulmonary artery pressures >50 mm Hg had mild TR or less, making the reliance on TRVmax for the measurement of EPASP unfeasible.[61] Our data indicate that PAAT could be a very important tool in deriving the EPASP and the EMPAP in the absence of sufficient TR and also demonstrate that PAAT can be used as a reliable alternative method for the derivation of both the EPASP and the EMPAP.

Our results and their implication on the usefulness of TTE in assessing the pulmonary hemodynamics non invasively can be summarized as follows. First, TRVmax was not measurable in 9.4% of patients, while PAAT was measurable in 100%. Of our patients with PH. This percentage may increase further if patients with borderline elevation of PA pressures were included in the study. Although saline injection may be useful in augmenting a weak or immeasurable TR signal, this method involves the insertion of an intravenous line and requires coordinated injection of agitated saline and color Doppler interrogation of the flow across the tricuspid valve. Though this technique may be useful, it is both resource and time consuming and thus shall not be optimal in a busy echocardiography laboratory. This underscores the need for an approach to pulmonary artery pressure measurement that is independent of the presence of TR and also justifies the use of a PAAT dependent method in the clinical echocardiography laboratory.

As with a previous study by Yared et al[63], we observed a strong and inverse correlation between PAAT and invasively obtained PASP among a cohort of patients with PH and with a wide range of PASP values. There was also a strong inverse correlation between PAAT and invasively derived MPAP values. This is in concurrence with previous studies[57,58].

The strength of the correlation was comparable to the correlation between TRPG derived EPASP and the invasively measured PASP (-0.93 Vs 0.94). Hence we propose that if studied in a larger cohort, this relationship can be quantified to find a regression

formula, as in the previous study by Yared et al[63], and thus make it feasible to derive not only the MPAP but also the PASP from the PAAT, in patients without sufficient TR too, so that the pulmonary hemodynamics can be accurately measured non invasively in a larger percentage of patients.

Several technical and physiologic issues pertaining to this study deserve mention. Though proximal pulmonary artery forward flow, as assessed by pulsed-wave Doppler, has a characteristic pressure-dependent pattern (i-e) the acceleration time becomes shorter as the pulmonary artery pressure increases, other factors, namely the heart rate, RV function, cardiac output, and the imaging technique, may affect its duration.[30] We accounted for the potential impact of heart rate variation in our study by correcting for heart rate with the RVET. Similar to other previously published studies,[57] we found these corrections to be unnecessary.

Because we were not able to control for cardiac output in our study, we cannot comment as to how cardiac output affected our findings, and so we remain uncertain about the accuracy of PAAT for deriving EPASP in patients with high cardiac output due to conditions like exercise or systemic vasodilation.

It has been shown that RV function can affect PAAT . RV systolic dysfunction tends to lengthen the PAAT.[64] In our study population, only 9 patients had RV dysfunction, and their removal and reanalysis of data did not affect our correlation results. Because of the small number of patients with RV dysfunction in our study, we

propose that our derivations from the study may not be accurate in patients with RV systolic dysfunction.

The imaging technique plays an important role in the measurement of PAAT that accurately reflects pulmonary pressure. Proper placement of the Doppler sample volume in the middle of the pulmonary artery and also its accurate alignment to the long axis of the main pulmonary artery are essential.

LIMITATIONS

Limitations in this study are that

1. The number of cases include in our study was small
2. We did not examine the performance of PAAT for the estimation of EPASP in conditions with high cardiac output, like volitional exercise or systemic vasodilation as in sepsis.
3. The proportion of cases due to lung disease, chronic thrombo embolic PH and due to idiopathic PH was small in our study.
4. Though the number of cases with RV systolic dysfunction, as measured by TAPSE, tricuspid s' and RV fractional area change was small in our study, there were a significant number of cases with RV diastolic dysfunction. The measurement of RV Tei index which is a marker of global RV function would have thrown more light on the impact of global RV function on the performance of PAAT for the derivation of MPAP and PASP. This was not done in our study.
5. The placement of Doppler sample volume during pulse-wave and continuous-wave Doppler examination at the center of the pulmonary artery is crucial to optimize the laminar flow pattern. Any deviation from this technique, like placing the sample volume close to the pulmonary artery wall, may change this flow pattern and thus render it unreliable.

CONCLUSION

PAAT is easily measurable in patients with pulmonary hypertension and strongly correlates with the values of pulmonary artery systolic pressure and the mean pulmonary artery pressure obtained by right heart catheterisation in a small population of patients with pulmonary hypertension due to a wide spectrum of illness, who underwent Trans Thoracic Echocardiographic (TTE) examination. This is comparable to the strong correlation between the previously well established method of deriving the EPASP from TRVmax and the invasively derived PASP. Adoption of a novel method of determining EPASP from PAAT shall increase significantly the number of patients in whom TTE can be used for the assessment of pulmonary hemodynamics non invasively.

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PERFORMA

NAME: **AGE/SEX:** **HT:** **WT:**

CD NO. **IP/OP no.** **CCL NO.**

D.O.A: **D.O.D:** **D.O.E:**

PRESENTATION: Chest pain Pedal edema

Dyspnoea Abd distension

Syncope Oliguria

Palpitation Fatigue

Other

PAST ILLNESS: Diabetes/SHT/COPD

ACS/ CVA

RHD/Other

PERSONAL HISTORY: Smoking/ Addictions

Occupation

MENSTRUAL HISTORY:

CLINICAL FEATURES: GE –

BP: PULSE:

CVS:

RS:

ABD: CNS:

Clinical Diagnosis:

Investigations: Hb: TC: DC: P L E M

RBS: Bl Urea: Sr. Creatinine:

Others:

ECG: Rate: Rhythm: P wave: PR int:

QRSD: QRS axis: ST: T :

ECHO data:

LVID d: LVID s: LVEF:

LVOT dia: LVOT VTI: HR: C.O. :

TR-derived values

TR Vmax (cm/sec) RA/RV gradient (mm Hg) :

EPSPAP (mm Hg)

Pulmonary artery–derived values

PAAT (ms) MPAP PAVmax (cm/sec)

RVET (msec) PAAT/RVET (m/sec2)

RVOT VTI PR EDP

RV Chamber dimensions

RV basal diameter cm RV subcostal wall thickness

RVOT PSAX distal diameter RVOT PLAX proximal diameter

IVC cm/collapse RA pr:

RV Systolic function

TAPSE cm Tricuspid s' cm/s FAC%

RV Diastolic function

E/A ratio — E/E' ratio —

Deceleration time (ms)

Right Heart Study:

Approach:	Catheters:	
RA pr:	RVSP:	RVEDP:
PASP:	PADP:	MPAP:
PAWP:		

MASTER CHART

S.No	Name	Age/Sex	History				Pulse	Hb	ECG	Diagnosis
			CP	S.O.B	RVF	Other				
1	Selvi	42/F	N	N	N	N	84	10.5	AF	Cor AVF
2	Ganesan	40/M	Y	Y	N	Old PT	80	16.1	RVH/RBBB	ASD/PHT
3	Pandiaraj	21/M	Y	Y	Y	S/P CMC	78	10.7	RVH	RHD
4	Arumugam	60/M	N	Y	N	K/C RHD	72	11.7	LAA/RAD	RHD
5	Sundari	32/F	N	Y	N		112	11.6	ST	CPTE
6	Ganesan	55/M	N	Y	N	K/C RHD	64	11.6	LVH	RHD
7	Sneha	14/F	N	N	N	RRTI	86	10.2	BVH	VSD/PHT
8	Gopalakrishnan	60/M	N	Y	N	K/C RHD	66	10	LVH	RHD
9	Jothimani	13/F	N	Y	N	RRTI	108	10.1	BVH	VSD/PDA/SMR
10	Booma	45/F	N	Y	N	RHD	98	12.3	LVH	RHD
11	Anbu	32/M	Y	Y	N	RF	72	13	LAA/RVH	RHD
12	Vellaisamy	45/M	Y	Y	N	N	72	13	LAA/LVH	RHD
13	Davamani	27/M	N	Y	N	N	70	13.5	IRBBB	ASD/PHT
14	Palaniammal	45/F	Y	N	N	Fever	100	10.6	RVH	SScl
15	Sangeetha	17/F	Y	Y	N	RF	80	10	N	RHD
16	Selsi	18/F	N	Y	N	N	67	9	RVH	PPH
17	Annapillai	35/F	N	Y	N	Scoliosis	100	11	RVH/AF	RHD
18	Nageswari	30/F	Y	Y	N	RRTI	92	12.8	CRBBB	ASD/PHT
19	Karpagavalli	15/F	Y	Y	N	N	75	16	RVH	PPH
20	Rekshalin Mary	26/F	N	Y	N	Postpartum	88	9	RAD	ASD/PHT
21	Vanniappan	65/M	Y	N	N	SHT	80	15.6	CRBBB/RAD	ASD/PHT

22	Latha	24/F	N	Y	N	Postpartum	78	13.1	RVH	ASD/PHT
23	Dhanushiya	16/F	N	Y	N	RRTI	64	14.6	CRBBB/LVH	AVCD
24	Poomayil	42/F	N	Y	N	N	100	19.8	N	CPTE
25	Ammaniammal	45/F	N	Y	N	Raynaud	92	9.9	RVH	SScl
26	Chinnapillai	38/F	N	Y	N	N	100	12	ST changes	CPTE
27	Nagarathinam	45/F	N	Y	N	RHD	98	12	LVH	RHD
28	Karuppiah	24/M	Y	Y	Y	S/P CMC	82	10.9	RVH	RHD
29	Angaian	42/M	Y	Y	N	Old PT	80	16	RVH	ASD/PHT
30	Gandhimathi	13/F	N	Y	N	RRTI	86	10.8	BVH	VSD/PHT
31	Bhagyam	38/F	Y	N	N	Fever	100	10	RVH	SScl
32	Chandra	21/F	Y	Y	N	RF	84	10.8	N	RHD
33	Sivalingam	60/M	N	Y	N	RHD	72	11.7	LAA/RAD	RHD
34	Vasanthi	20/F	N	Y	N	N	**68**	9.8	RVH	Cystic lung
35	Meera	15/F	N	Y	N	RRTI	104	10	BVH	PDA
36	Muthiah	55/M	N	Y	N	RHD	64	11.6	LVH	RHD
37	Chellammal	37/F	N	Y	N	S/P CMC	98	11	RVH/AF	RHD
38	Pandiammal	33/F	Y	Y	N	RRTI	90	12	CRBBB	ASD/PHT
39	Ammasi	51/M	N	Y	N	RHD	68	11.9	LVH	RHD
40	Jayalakshmi	21/F	Y	Y	N	N	78	15.8	RVH	PPH
41	Mohamed Siddique	33/M	N	Y	N	RF	70	13	LAA/RVH	RHD
42	Subramanian	45/M	Y	Y	N	N	78	13.1	LAA/LVH	RHD
43	Sivagami	28/F	N	Y	N	Postpartum	86	9.8	RAD	ASD/PHT
44	Gangaraman	29/M	N	Y	N	N	71	11.8	RVH	ILD
45	Indrani	26/F	N	Y	N	Postpartum	82	13.1	RVH	ASD/PHT
46	Rajapandian	28/M	N	Y	N	N	74	13.5	IRBBB	ASD/PHT
47	Muthupetchi	17/F	N	Y	N	RRTI	68	14.6	CRBBB	AVCD
48	Saroja	45/F	N	Y	N	Raynaud	96	10	RVH	SScl

49	Alagusundaram	65/M	Y	N	N	N	82	15.8	CRBBB	ASD/PHT
50	Kamatchi	19/F	N	Y	N	N	70	9.9	RVH	PPH
51	Usharani	18/F	Y	Y	N	N	80	16.1	RVH	PPH
52	Thirukkammal	23/F	Y	Y	N	RF	78	10.9	N	RHD
53	Boopalan	31/M	N	Y	N	N	78	12.8	IRBBB	ASD/PHT

MASTER CHART

S.No	Name	RV dimension cm				Echo hemodynamics						
		Basal	RVOT Prox	RVOTdist	RV wall	TRPG mmHg	RAPmmHg	EPASPmmHg	PAATms	RVET ms	EPADPmmHg	EMPAPmmHg
1	Selvi	4.1	3.3	2.8	0.5	37	3	40	85	249		37.3
2	Ganesan	4	3.8	3.5	0.9	78	8	86	77	285	18	47.7
3	Pandiaraj	4.1	3.8	3	0.8	63	4	66	86	246	25	37
4	Arumugam	3.6	3.4	2.8	0.8		5		77	295		42
5	Sundari	3.3	3.3	2.5		36	5	41	94	240		32
6	Ganesan	2.9	2.4	2	0.5	34	5	39	100	244		28
7	Sneha	3.4	2.7	2.5	0.6	93	5	98	64	278	18	50.3
8	Gopalakrishnan	2.8	2.3	2	0.6		8		90	246		34
9	Jothimani	3.1	2.7	2.4	0.7	99	5	104	57	285		54.6
10	Booma	2.8	2.6	2.4	0.6	33	5	38	96	246		31
11	Anbu	3.2	2.4	2	0.6	32	5	37	90	248		34.2
12	Vellaisamy	3.9	3.4	2.9	0.6	54	5	59	87	239	15	36
13	Davamani	4.1	4.1	4	0.7	40	5	45	96	246		30.4
14	Palaniammal	3.8	3.3	3.1	0.5	60	3	63	65	282		50.2
15	Sangeetha	3	2.6	2.4	0.6	73	5	78	64	294		50.3
16	Selsi	2.8	3.2	2.8	0.6	101	5	106	60	289	30	52.8

17	Annapillai	3.9	2.5	2.4	0.8	85	5	100	67	279		49
18	Nageswari	3.8	3.2	2.9	0.7	66	5	71	81	271	20	39.7
19	Karpagavalli	3.2	2.6	2.6	0.7	94	5	99	66	275	37	49
20	Rekshalin Mary	3.7	3	2.8	0.6	46	5	51	89	240	18	34.8
21	Vanniappan	3.5	2.6	2.3	0.8	60	5	65	70	282		46.6
22	Latha	4.2	3.7	3.2	0.6	91	5	96	60	289	35	52.8
23	Dhanushiya	3.7	3.4	3.4	0.7	98	8	106	63	288		50.9
24	Poomayil	3.3	3.4	2.5	0.6	36	5	41	94	240	10	32
25	Ammaniammal	3.7	3.4	3	0.6	58	5	63	74	285		44.1
26	Chinnapillai	3.7	3.3	2.5	0.6	48	5	53	90	240		34.2
27	Nagarathinam	2.8	2.6	2.4	0.6	33	5	38	96	246		31
28	Karuppiah	4.1	3.8	3	0.8	63	5	68	85	254	28	37.4
29	Angaian	4	3.8	3.5	0.9	78	8	86	77	249	18	47.7
30	Gandhimathi	3.4	2.7	2.7	0.6	93	5	98	63	282	18	50.8
31	Bhagyam	3.8	3.3	3.1	0.6	59	5	64	66	278		49.7
32	Chandra	3	2.6	2.4	0.6	79	5	84	64	262		50.3
33	Sivalingam	3.6	2.4	2.8	0.6		5		77	285		42
34	Vasanthi	3.2	3.2	2.8	0.6	81	5	86	60	289	32	52.8
35	Meera	3.4	2.9	2.8	0.7	93	5	98	57	282		54.6
36	Muthiah	2.9	2.4	2	0.5	35	5	40	101	250		27.8
37	Chellammal	3.9	2.6	2.6	0.9	84	15	99	67	279		49
38	Pandiammal	3.9	3.5	3.2	0.7	65	5	70	81	270	22	39.7
39	Ammasi	3	2.6	2.2	0.5		5		100	292		28
40	Jayalakshmi	3.2	2.6	2.6	0.7	94	5	99	66	275	36	49
41	Mohamed Siddique	3.2	2.4	2.1	0.6	32	5	37	90	243		34.2
42	Subramanian	3.9	3.4	2.9	0.6	53	5	58	87	240	18	36
43	Sivagami	3.7	3.1	2.8	0.6	46	5	51	89	248	18	34.8

44	Gangaraman	3.3	3.2	2.9	0.6	90	5	95	60	280	32	52.8
45	Indrani	4.2	3.7	3.2	0.6	90	5	95	60	289	36	52.8
46	Rajapandian	4.3	4.1	4	0.7	40	5	45	96	246		30.4
47	Muthupetchi	3.7	3.4	3.3	0.7	96	6	102	63	287		50.9
48	Saroja	3.7	3.4	3.1	0.6	58	5	63	74	285		44.1
49	Alagusundaram	4	3.2	2.8	0.8	61	5	66	70	280		46.6
50	Kamatchi	3.2	3	2.9	0.6	93	5	98	60	280	31	52.8
51	Usharani	3.6	2.9	2.8	0.7	100	5	105	66	275	31	49
52	Thirukkammal	2.1	2.7	2.5	0.6	68	6	74	64	262		50.3
53	Boopalan	4.1	4.1	4	0.7	43	5	48	90	240		34.2

MASTER CHART

S.No	Name	RV Sys Fn			RV dia fn			Invasive Pressures (mmHg)						
		TAPSEcm	Tric s'cm/s	FAC%	E/A	E/e'	DT ms	PAWP	PASP	PADP	MPAP	RVSP	RVEDP	RAP
1	Selvi	2	15	58		4.6	165	9	50	22	37	51	10	18
2	Ganesan	2.6	17	60	0.75	4.75	194	8	70	24	44	66	15	12
3	Pandiaraj	0.9	6.9	22	0.79	9.5	106	18	58	28	39	61	3	4
4	Arumugam	1.9	12	50	0.71	6.75	204	16	70	28	41	69	5	6
5	Sundari	2.7	17	54	0.6	5.2	140	9	39	17	30	40	12	9
6	Ganesan	3	13	53	1.5	6.8	180	18	38	18	29	42	10	6
7	Sneha	2.8	17	49	1.28	6.8	113	8	104	26	48	99	10	8
8	Gopalakrishnan	1.8	11	40	1.26	8.6	165	22	55	25	35	55	12	9
9	Jothimani	1.8	14	41	1.32	5	120	21	90	40	55	100	10	12
10	Booma	2.2	16	50	0.84	4.72	128	18	51	18	31	47	10	6
11	Anbu	2.4	14	51	1.4	3.25	148	32	48	29	37	52	9	8
12	Vellaisamy	1.9	15	59	1.5	8	109	26	50	26	35	46	3	5
13	Davamani	2.9	15	50	1.75	9.8	137	8	43	18	31	45	8	5
14	Palaniammal	1.9	10	35	1	5.5	106	8	61	24	38	63	10	10
15	Sangeetha	2.5	14	45	1.21	8.8	194	27	73	31	51	72	8	8
16	Selsi	1.4	10	34	1.51	13	204	13	96	39	57	97	10	11
17	Annapillai	1.3	10	35		8	201	30	106	31	49	100	10	11
18	Nageswari	1.2	7	27	1	6.5	280	10	78	24	42	81	12	11

19	Karpagavalli	1.7	12	41	1.2	3.9	244	9	100	38	52	104	12	12
20	Rekshalin Mary	2.9	19	56	1	6.2	243	8	55	24	34	58	11	10
21	Vanniappan	2.7	16	52	0.6	5.8	342	10	72	37	49	77	12	11
22	Latha	1.9	12	40	0.8	6.4	180	9	88	39	55	92	9	8
23	Dhanushiya	1.9	10	34	1.1	4.8	201	9	98	29	49	102	8	8
24	Poomayil	2.7	17	55	0.8	5.8	200	9	39	17	30	40	12	9
25	Ammaniammal	1.7	13	43	1.1	5.7	126	8	69	31	45	68	9	8
26	Chinnapillai	2.4	18	58	0.6	5.8	138	9	48	21	33	50	12	9
27	Nagarathinam	2.2	16	57	0.84	4.7	129	18	50	18	32	47	10	7
28	Karuppiah	0.9	6.1	27	0.8	8.7	106	18	58	29	38	61	4	4
29	Angaian	2.6	17	59	0.75	5.5	196	8	70	24	44	66	15	12
30	Gandhimathi	2.8	16	57	1.27	6.4	113	8	104	26	48	99	10	8
31	Bhagyam	1.9	10	35	1.1	5.8	120	9	64	24	39	68	9	8
32	Chandra	2.5	14	47	1.2	7.8	194	27	74	29	50	76	8	8
33	Sivalingam	1.9	12	42	0.71	6.75	206	16	70	28	41	69	5	6
34	Vasanthi	1.4	10	34	1.6	10	204	13	96	39	55	97	10	11
35	Meera	1.8	14	49	1.32	5	120	9	92	43	58	92	10	9
36	Muthiah	3	13	45	1.5	6.8	180	15	39	18	28	44	10	11
37	Chellammal	1.3	10	34		8	201	27	108	30	47	102	10	11
38	Pandiammal	1.2	7	27	1	6.5	280	10	72	24	42	76	12	11
39	Ammasi	2.9	17	57	1.2	6	171	16	40	17	29	42	10	10
40	Jayalakshmi	1.7	12	40	1.2	3.9	244	9	100	38	52	102	10	10
41	Mohamed Siddique	2.4	14	47	1.3	3.25	148	30	49	28	38	52	9	8
42	Subramanian	1.9	15	50	1.5	8	109	26	50	20	35	46	4	4
43	Sivagami	2.9	20	60	1	6.2	243	8	55	24	34	58	11	10
44	Gangaraman	1.6	13	44	1.53	9.1	201	10	92	39	54	97	8	8
45	Indrani	1.9	14	47	0.8	6.4	180	9	88	39	55	90	9	8

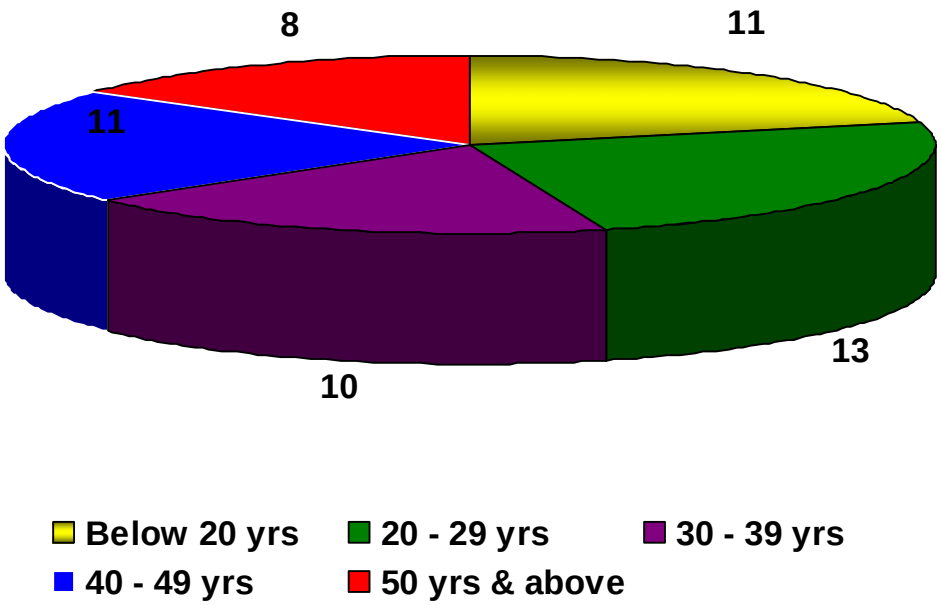
46	Rajapandian	2.9	15	54	1.76	9.8	137	8	43	18	31	45	8	7
47	Muthupetchi	1.4	10	35	1.1	6.8	204	9	98	31	38	100	10	9
48	Saroja	1.7	13	45	1.1	5.7	126	8	69	31	45	67	8	8
49	Alagusundaram	2.7	16	55	0.6	5.8	142	11	70	37	48	77	12	11
50	Kamatchi	1.7	14	49	1.4	9.4	204	9	90	39	55	93	10	11
51	Usharani	1.8	14	50	1.2	4.2	240	9	96	36	50	99	9	8
52	Thirukkammal	2.6	17	58	1.21	8.8	192	24	73	30	49	76	8	8
53	Boopalan	2.6	14	51	1.61	6.8	120	8	49	19	33	50	8	7

INTRODUCTION

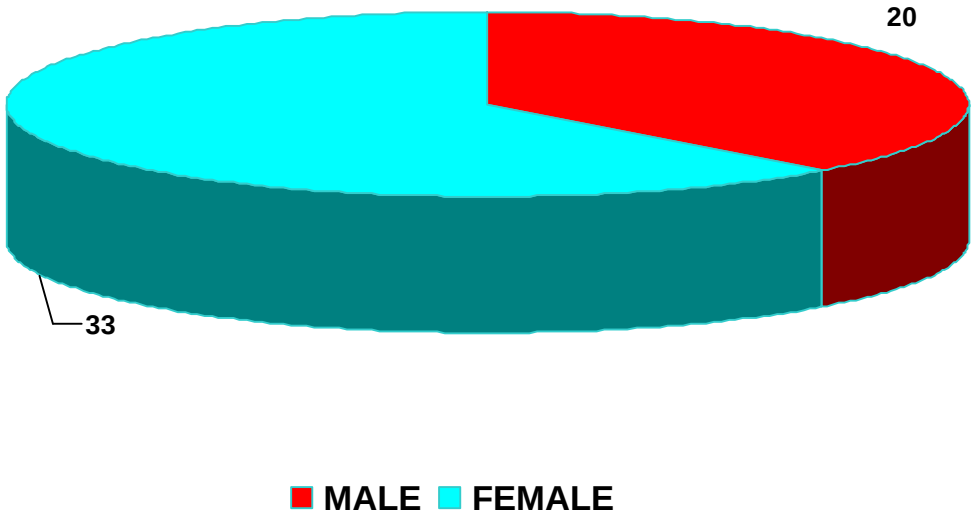
Two decades ago pulmonary hypertension (PH) was seen as a serious illness with a survival of 2.8 years from its diagnosis. Significant progress has been made in this field in the last ten to fifteen years in the understanding of the pathophysiology and also the treatment of PH. In the past, even though physicians diagnosed PH, treatment of this condition was not rewarding and patients almost always succumbed to the disease. The discovery of prostacyclin by Sir John Vane has since made a revolution in the treatment of PH1.

PH is a disease that results from reduction in the quantity of blood flowing across the pulmonary circulation, that causes an increase in pulmonary vascular resistance (PVR) and ultimately to right ventricular failure2 Excessive proliferation of the endothelial lining cells of the pulmonary vasculature and reduced apoptosis of the same leads

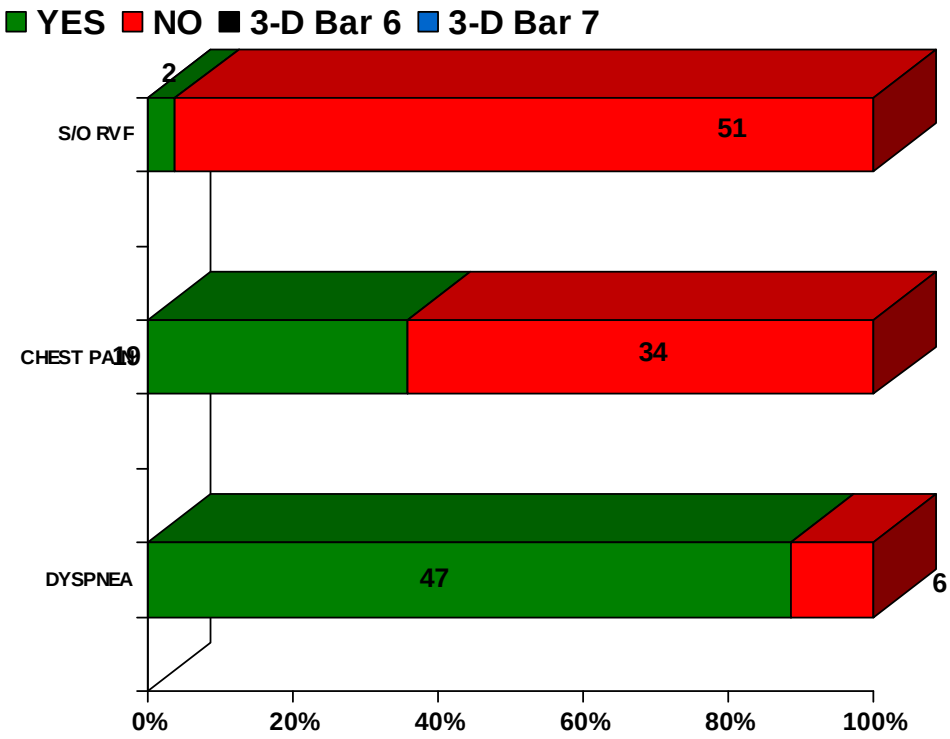
AGE DISTRIBUTION OF THE STUDY POPULATION



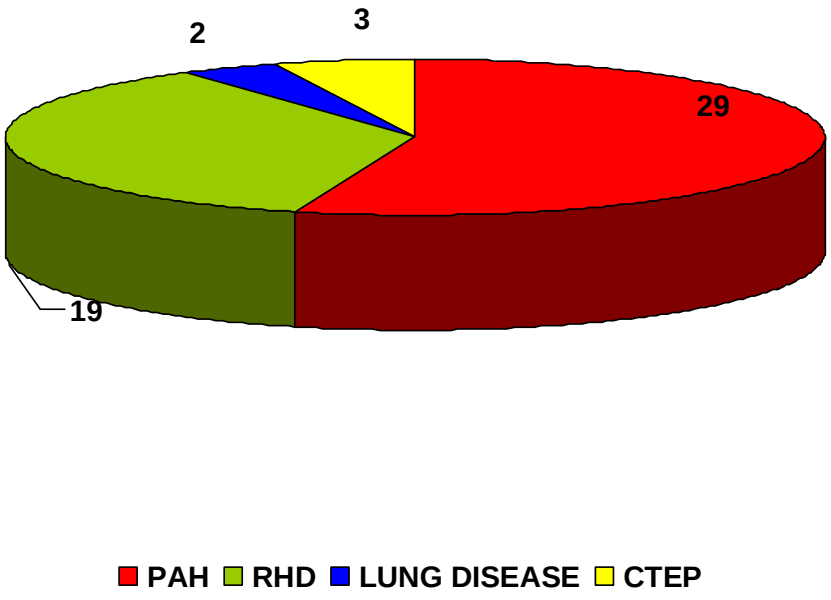
SEX DISTRIBUTION OF THE STUDY POPULATION



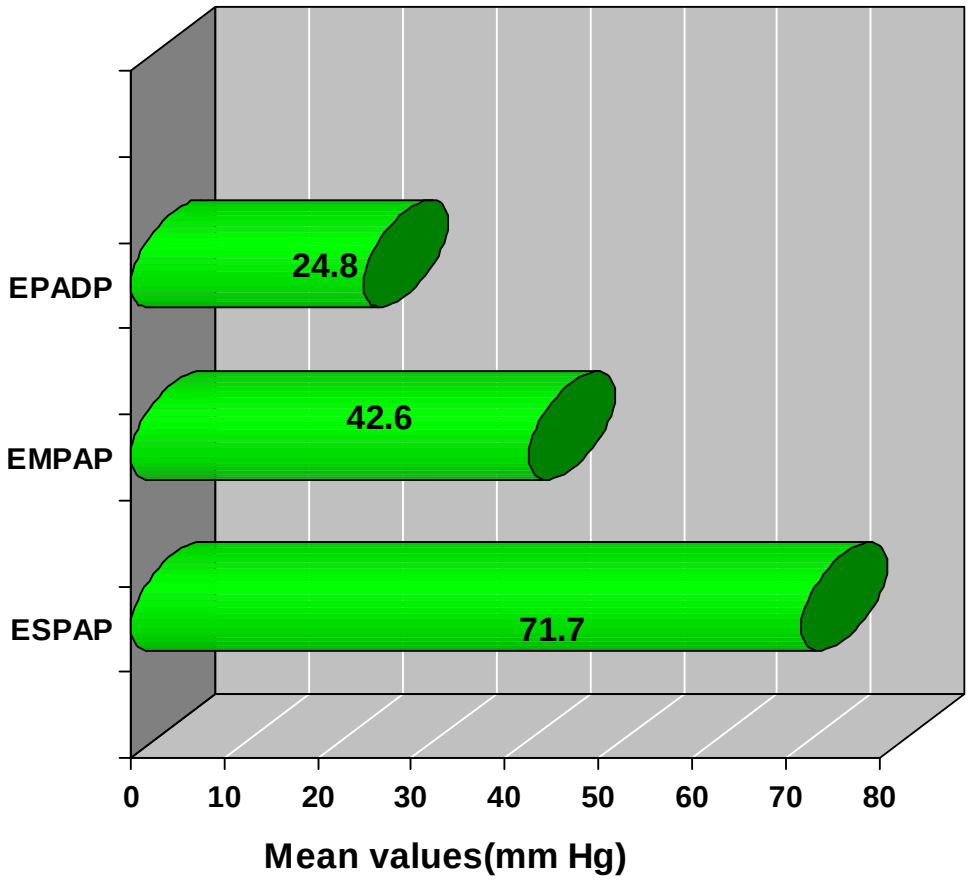
SYMPTOMS


YES
NO
3-D Bar 6
3-D Bar 7
2
51
S/O RVF
19
34
CHEST PAIN
47
6
DYSPNEA
0%
20%
40%
60%
80%
100%

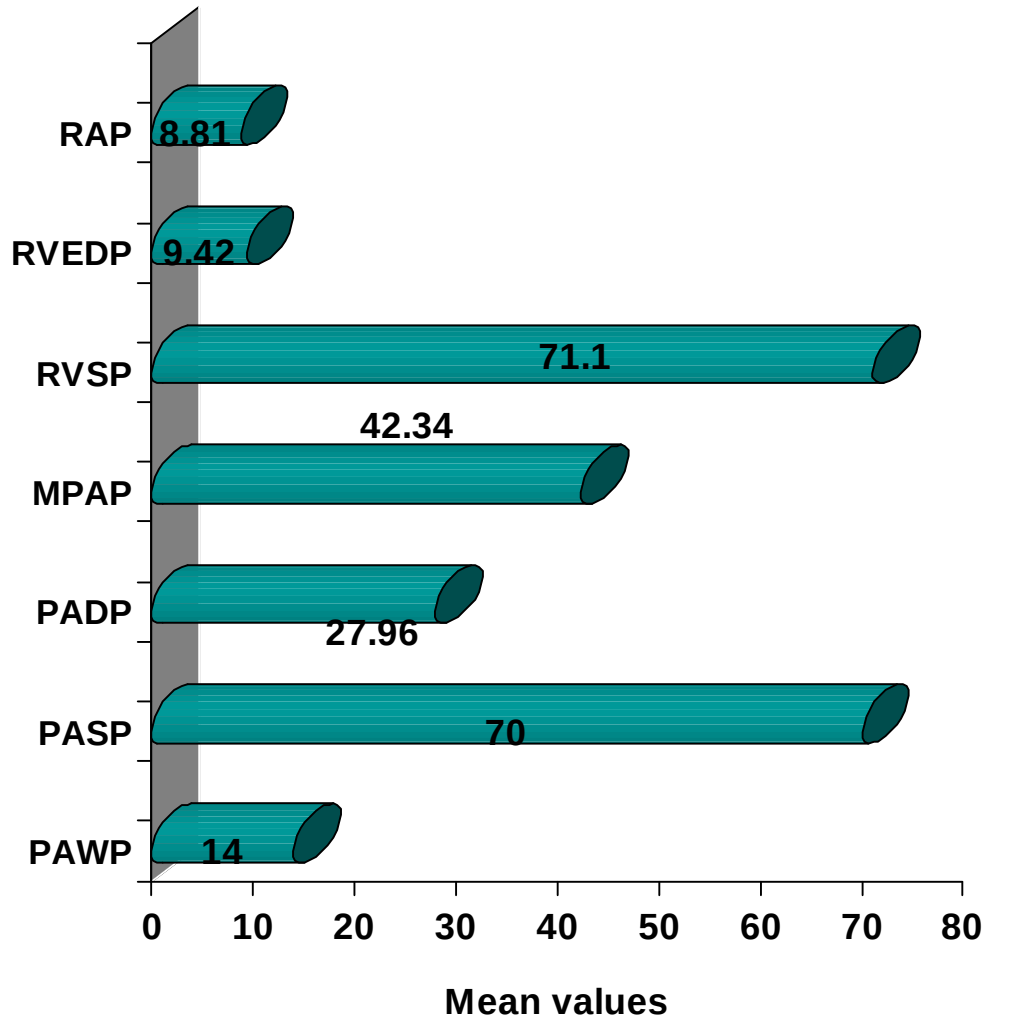
DIAGNOSIS



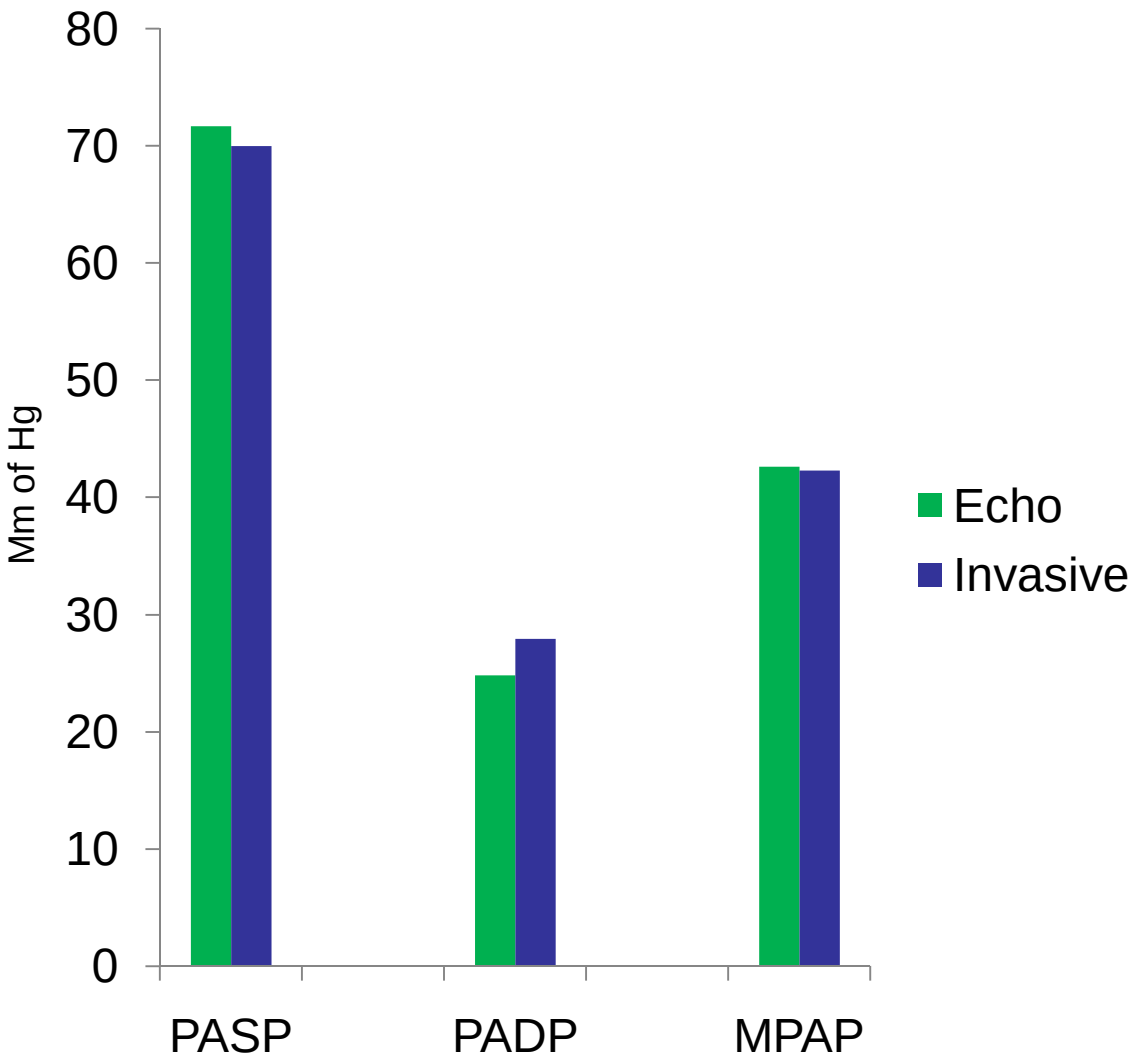
ECHO DERIVED PULMONARY ARTERY PRESSURES



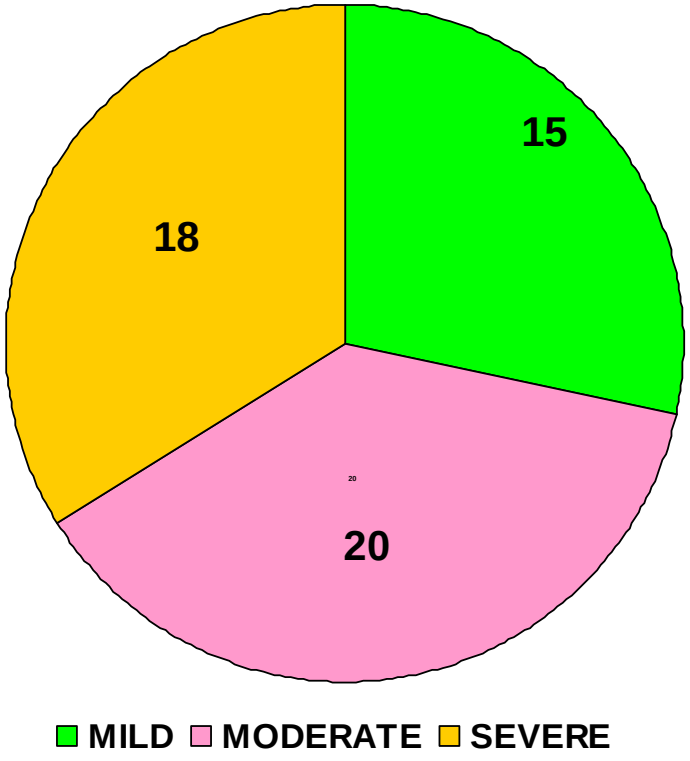
INVASIVELY OBTAINED PRESSURES



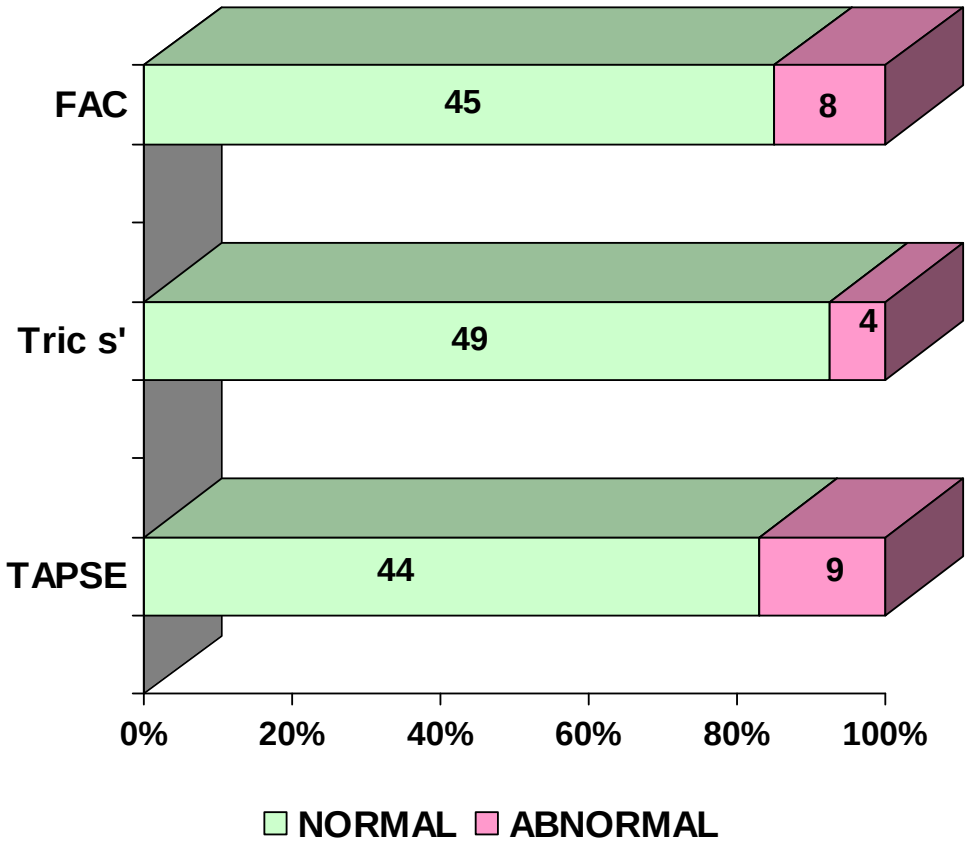
COMPARISON OF ECHO AND INVASIVELY DERIVED PULMONARY ARTERY PRESSURES



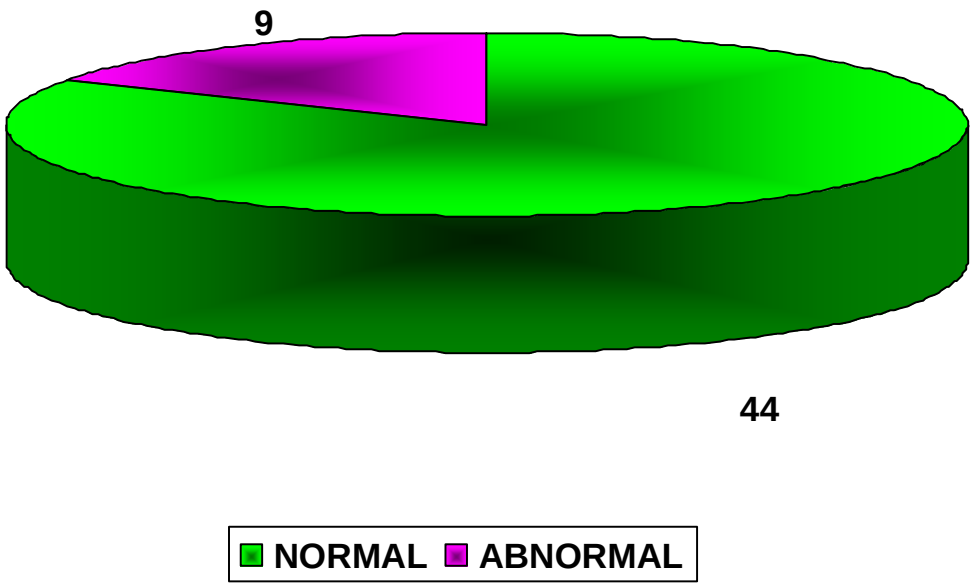
SEVERITY OF PH



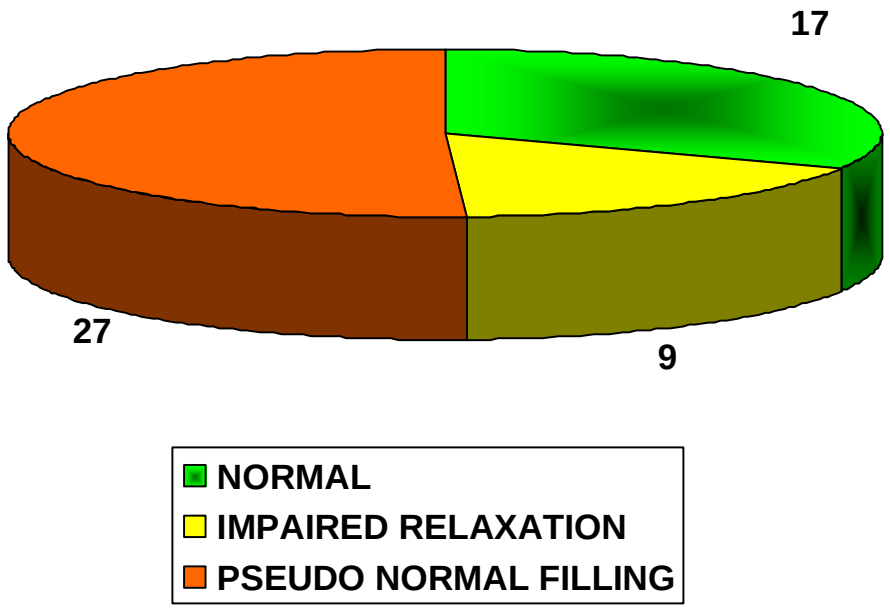
RIGHT VENTRICULAR
SYSTOLIC FUNCTION



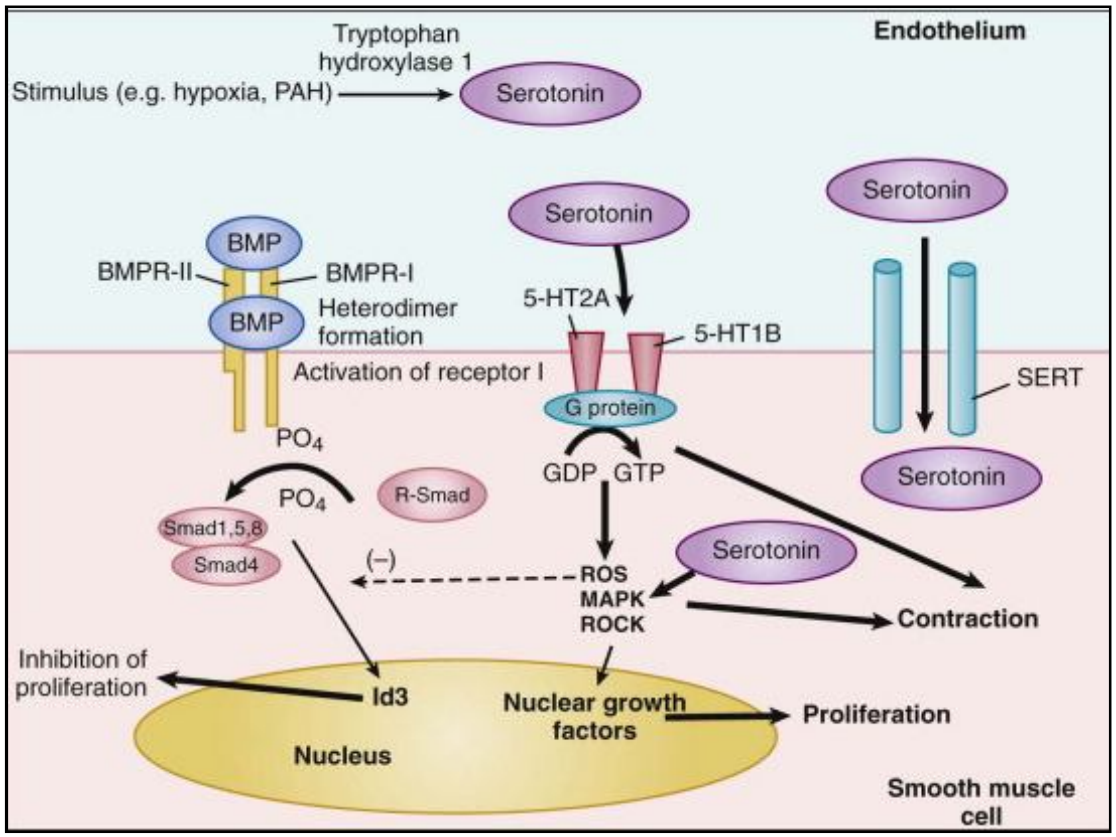
RV SYSTOLIC FUNCTION



RV DIASTOLIC FUNCTION



Molecular mechanisms of cellular proliferation–mediated remodeling in PH

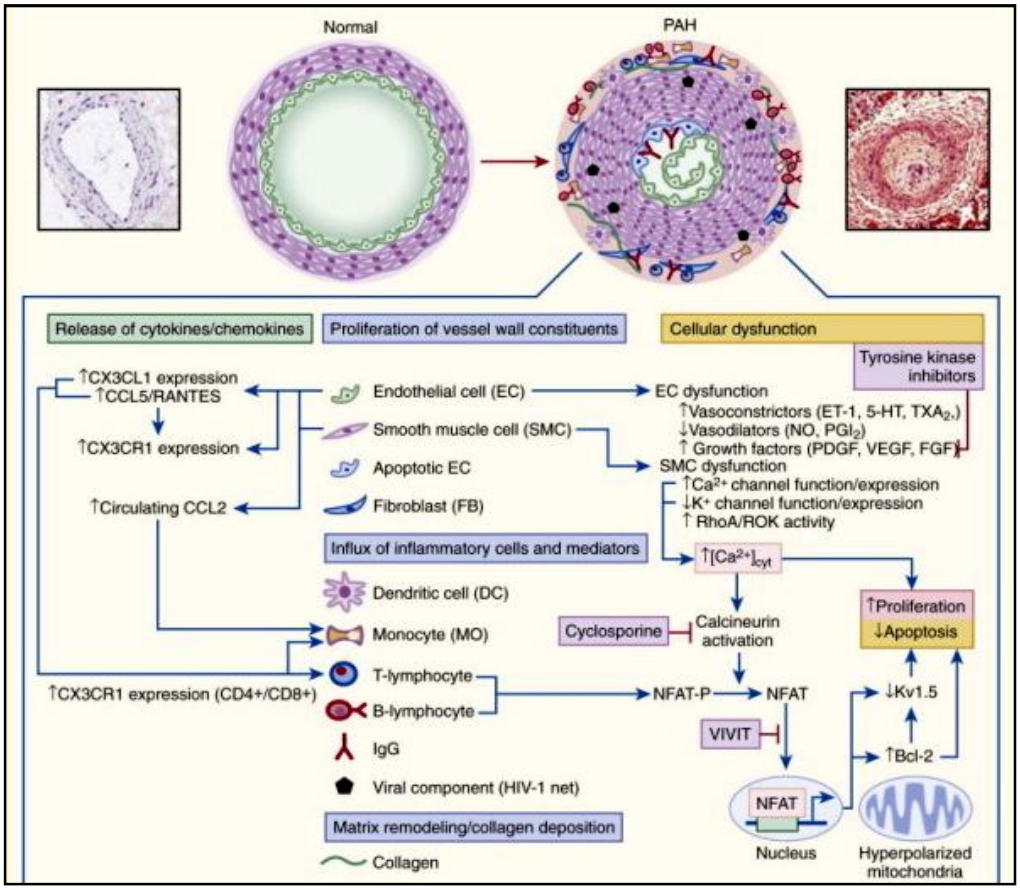


Serotonin synthesis via tryptophan hydroxylase 1 acts in a paracrine fashion on underlying PASMCs. This may contribute to contraction and increase the expression of nuclear growth factors leading to proliferation. Serotonin may also stimulate 5-hydroxytryptamine (5-HT) 1A and 2B receptors to induce contraction and ROS, ROCK, and MAPK activation.

Signaling by wild-type BMPRII involves heterodimerization with the transmembrane serine-threonine kinases type I BMPR-IA and BMPR-IB receptors at the cell membrane. On ligand binding, the constitutively active BMPR-II phosphorylates the type I receptor. Activated type I receptors phosphorylate the cytoplasmic signaling proteins known as receptor-mediated Smads (R-Smads) 1, 5, and 8. These complex with Smad4 and translocate to the nucleus, where they activate downstream target genes such as the inhibitors of DNA binding 3 (Ids), which inhibit proliferation.

Serotonin may antagonize the antiproliferative BMPR-II/Smad pathway, inhibit Id3 activation, and facilitate proliferation. *(–) = inhibitory effect.*

Molecular mechanisms of inflammation-mediated remodeling in PH

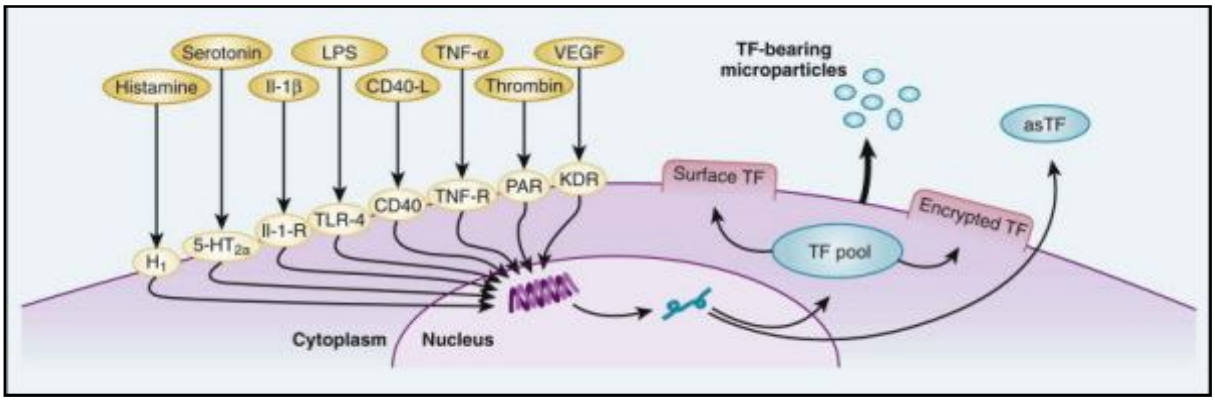


This schematic features inflammatory mediators, cells, and mechanisms involved in pulmonary vascular remodeling as well as potential therapeutic targets.

*(bcl2 = B-cell lymphoma 2; CCL2 = chemokine (C-C motif) ligand 2; CCL5 = chemokine (C-C motif) ligand 5 or RANTES (**r**egulated upon **a**ctivation, **n**ormal **T** cell **e**xpressed and **s**ecreted); CX3CL1 = chemokine (C-X3-C motif) ligand 1 (fractalkine); CX3CR1 = chemokine (C-X3-C motif) receptor 1; DC = dendritic cells; FB = fibroblasts; FGF = fibroblast growth factor; 5-HT = serotonin; HIV-1 = human immunodeficiency virus 1; IgG = immunoglobulin G; MO = monocyte; PGI2 = prostacyclin; ROK = rho kinase.)*

(From Hassoun PM, Mouthon L, Barbera JA, et al: Inflammation, growth factors, and pulmonary vascular remodeling. J Am Coll Cardiol 54:S10, 2009.)

Molecular mechanisms of thrombosis-mediated remodeling in PH

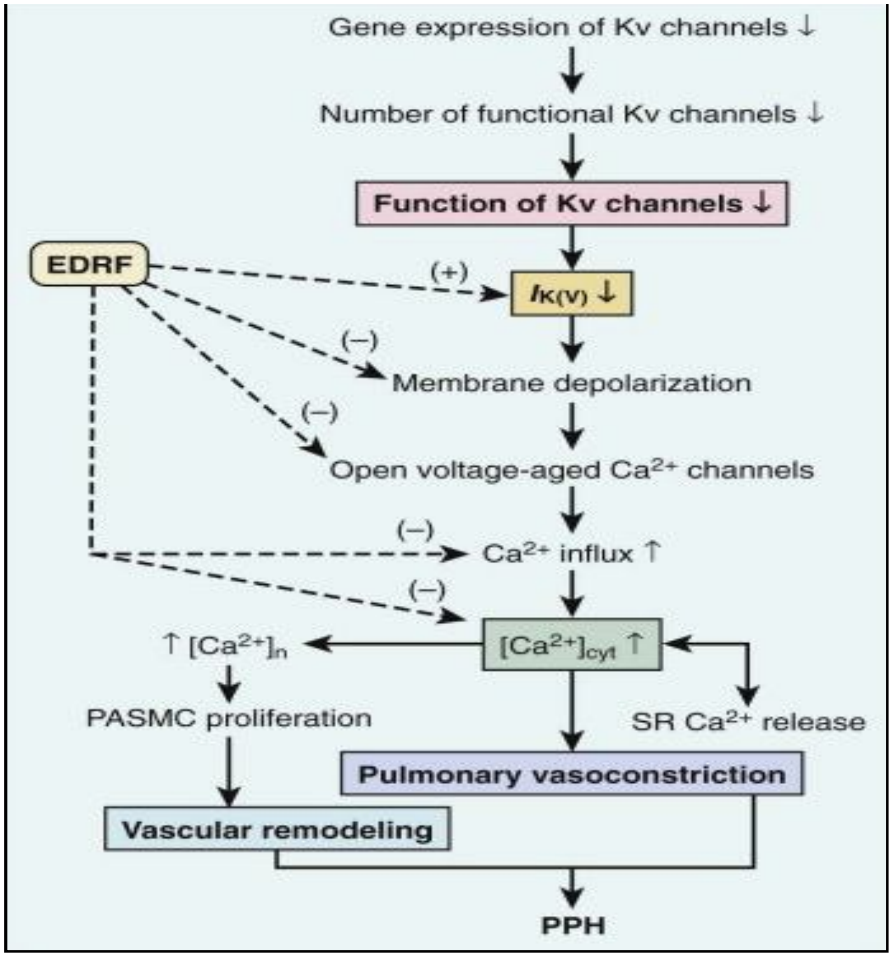


Various mediators induce tissue factor TF expression through activation of their receptors. Induction of TF primarily occurs at the transcriptional level, resulting in an increase in TF mRNA and, eventually, in TF protein expression. TF is distributed in three cellular pools as cytoplasmic TF, surface TF, and encrypted TF. Moreover, TF-containing microparticles are released from the cell. Alternative splicing results in a soluble secreted form of TF (asTF).

(CD40-L = CD40-ligand; H_1 = histamine H1 receptor; 5-HT_{2a} = 5-hydroxytryptamine 2a receptor; IL-1-R = interleukin-1 receptor; KDR = VEGF receptor 2; LPS = lipopolysaccharide; PAR = protease-activated receptor; TLR-4 = TolI-like receptor 4; TNF-R = tumor necrosis factor receptor.)

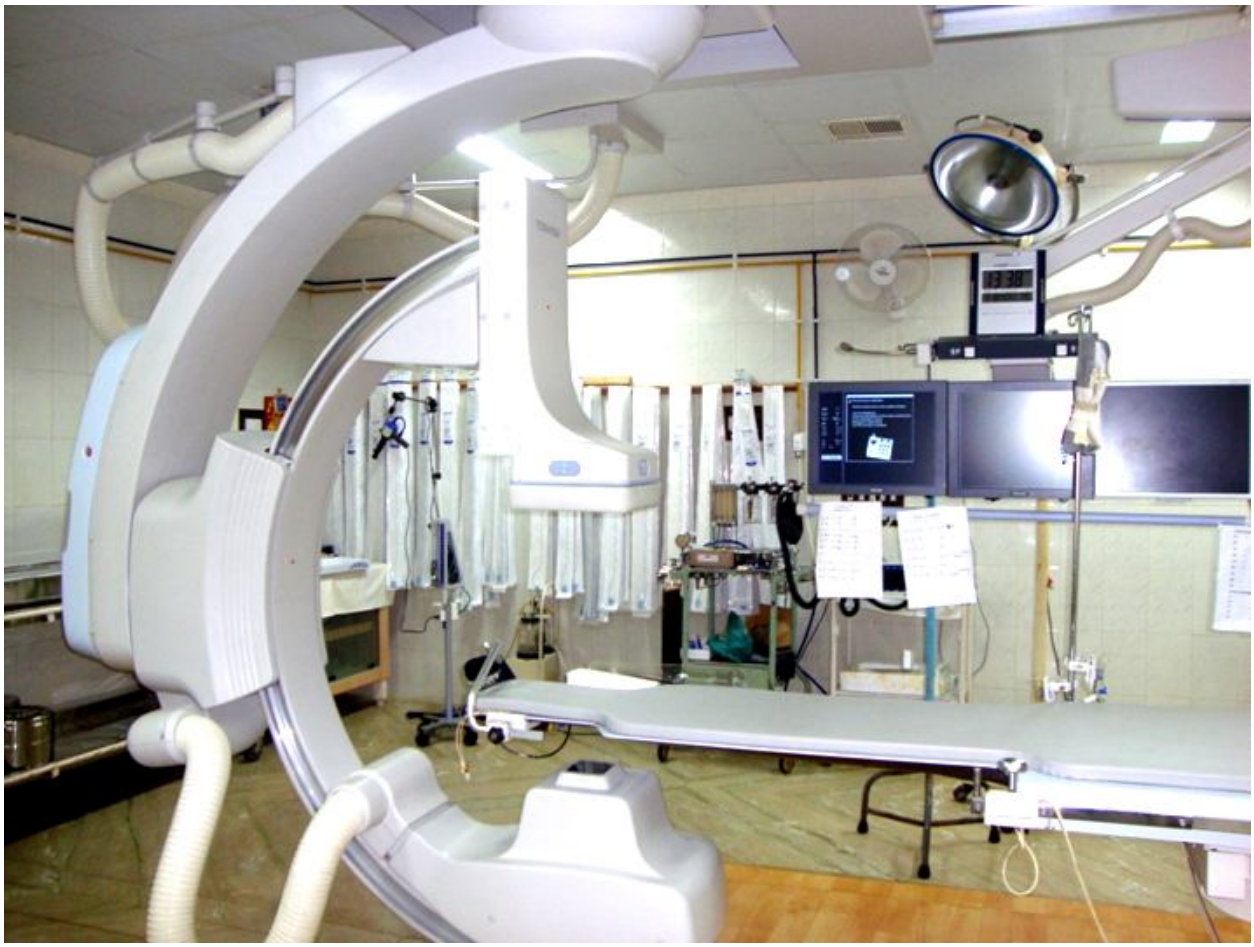
(From Steffel J, L?scher TF, Tanner FC: Tissue factor in cardiovascular diseases: Molecular mechanisms and clinical implications. Circulation 113:722, 2006.)

Molecular mechanisms of vasoconstriction-mediated remodeling in PH



The process may be initiated by abnormal gene transcription and expression of Kv channels. Resultant reduction of Kv currents [$I_{K(V)}$] causes membrane depolarization and opens voltage-gated Ca^{2+} channels. Increased Ca^{2+} influx through sarcolemmal Ca^{2+} channels and Ca^{2+}-induced Ca^{2+} release from intracellular Ca^{2+} stores (mainly sarcoplasmic reticulum [SR]) raise cytoplasmic Ca^{2+} concentrations ($[Ca^{2+}]_{cyt}$), which triggers pulmonary vasoconstriction. Endothelium-derived relaxing factors (EDRFs) may participate in regulating Em and $[Ca^{2+}]_{cyt}$ through activation of K^+ (KCa and Kv) channels and/or inhibition of voltage-gated Ca^{2+} channels in PASMCs. (+) = increase (or enhance); (–) = decrease (or inhibit).

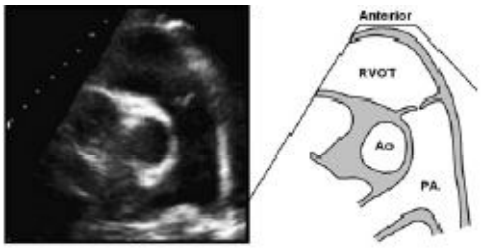
(From Yuan J, Aldinger A, Juhaszova M, et al: Dysfunctional voltage-gated K^+ channels in pulmonary artery smooth muscle cells of patients with primary pulmonary hypertension. Circulation 98:1400, 1998.)



Cadiac catheterisation laboratory

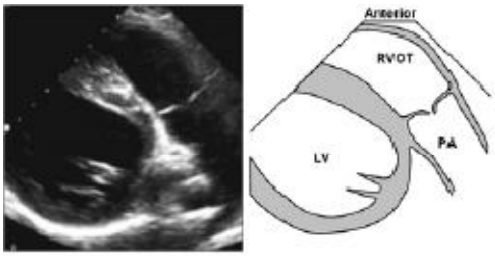
Philips IE 33 Echo machine

ECHOCARDIOGRAPHIC VIEWS



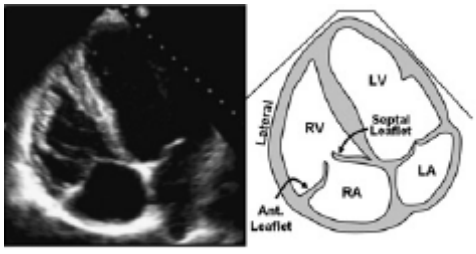
Parasternal short-axis of bifurcation of the PA

Shows the anterior RVOT in its long axis view, the infundibulum, pulmonary valve and the MPA. Used to measure the RVOT dimension and to assess the pulmonary valve



Parasternal long-axis of RVOT and PA

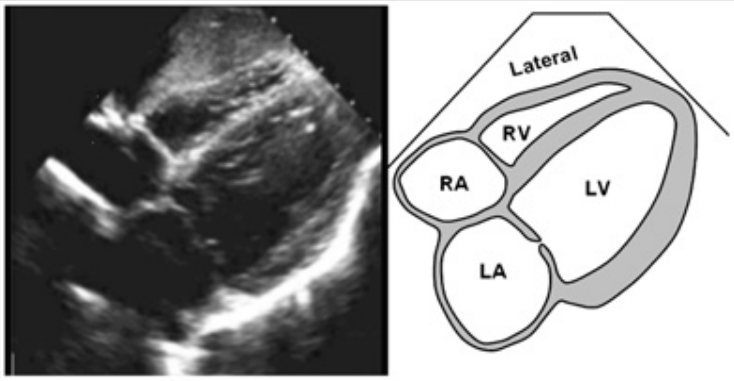
Doppler measurement of infundibulum, pulmonary valve and pulmonary artery are done in this view



RV focused apical 4-chamber

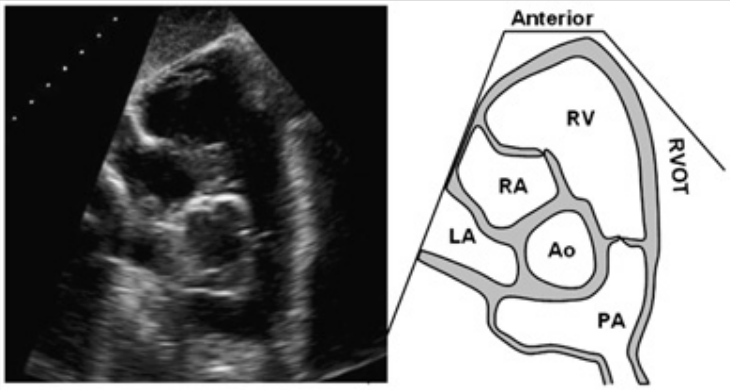
RA and RV size, area, shape and function and the TR jet are assessed in this view

ECHOCARDIOGRAPHIC VIEWS



RV subcostal 4-chamber

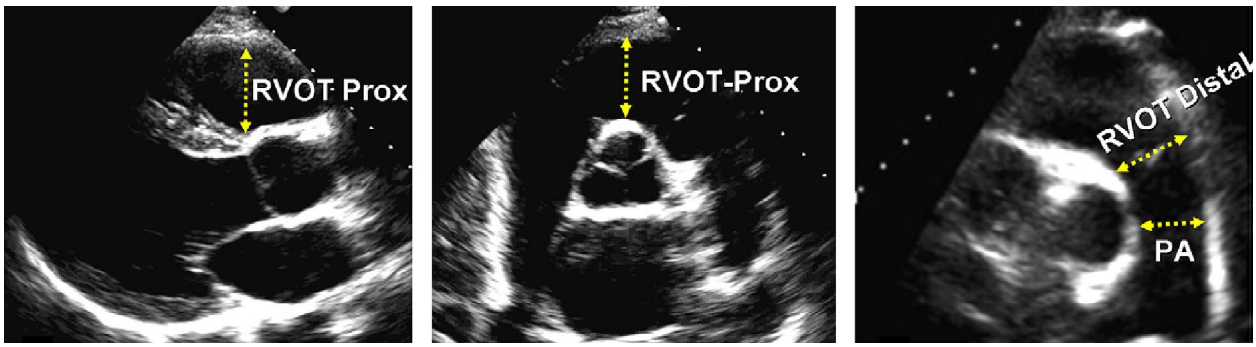
- The RV wall thickness is best measured in this view.
- It is useful for evaluation of the RV/RA wall inversion/collapse in diagnosing patients with cardiac tamponade.
- ASD and PFO are often best shown in this view with 2D and color Doppler.
- Used to visualize but not quantify RV/RA sizes due to its foreshortened and oblique angle.
- TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.



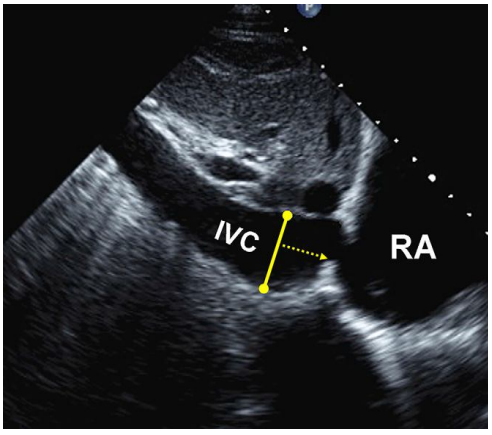
Subcostal short-axis of basal RV

- Base of the RV wall including RV inflow, RV outflow, pulmonary valve, pulmonary artery and its branches are well visualized.
- RVOT dimension can also be measured in this view.
- Used for Doppler measurement of the infundibulum, pulmonary valve and pulmonary artery

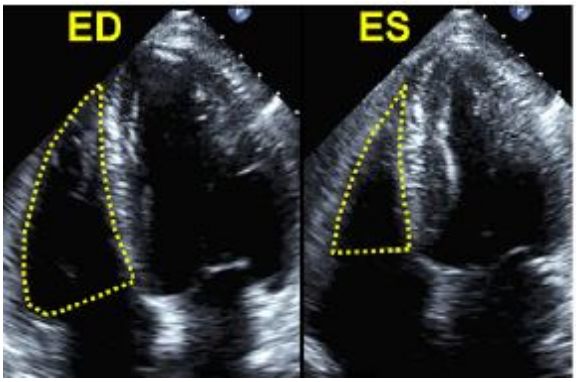
ECHOCARDIOGRAPHIC MEASUREMENTS



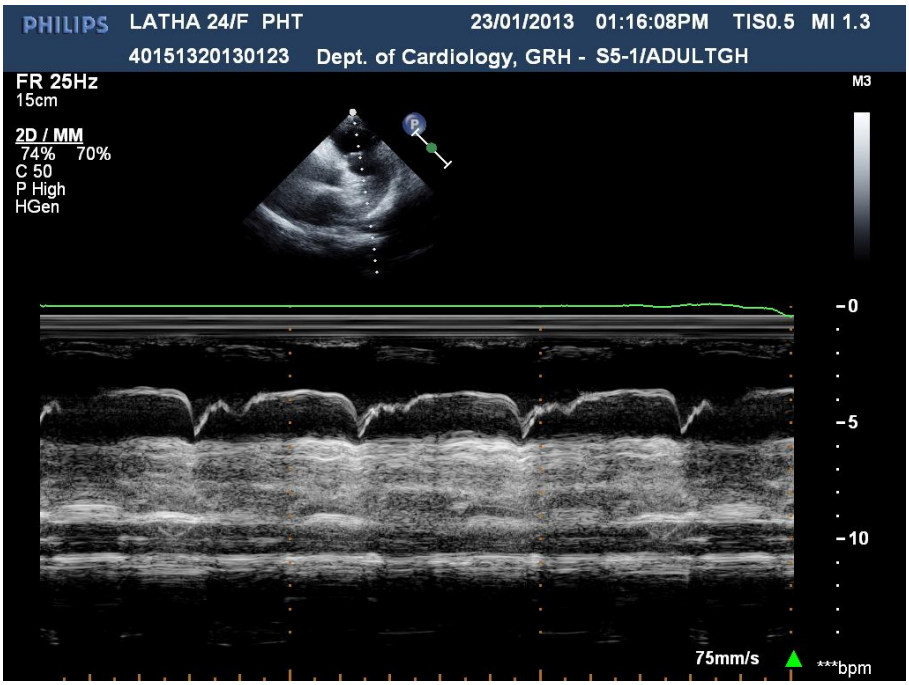
Measurement of right ventricular outflow tract (RVOT) dimensions



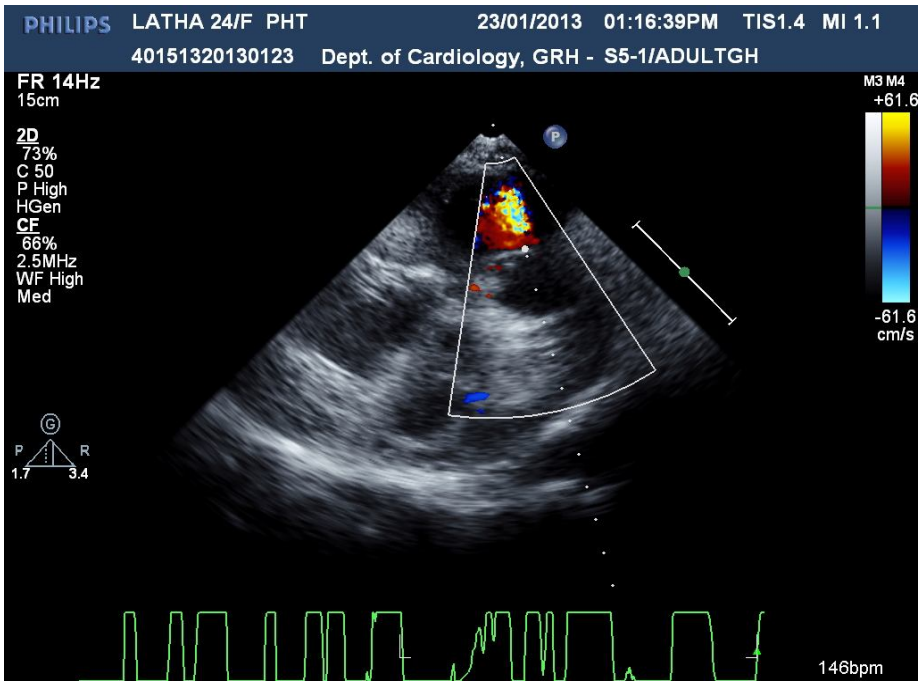
IVC diameter



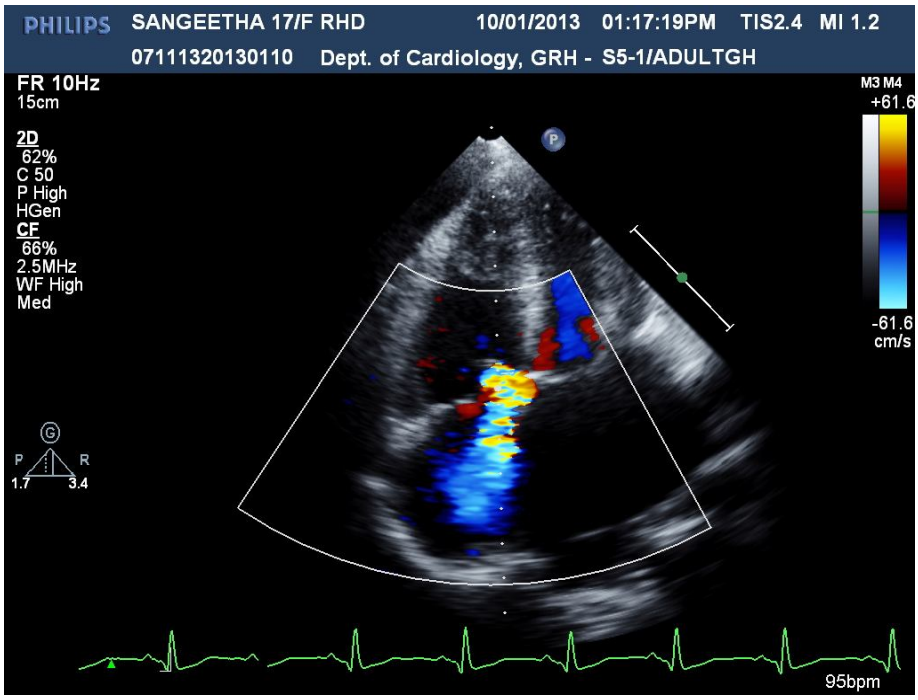
RV fractional area change(FAC)



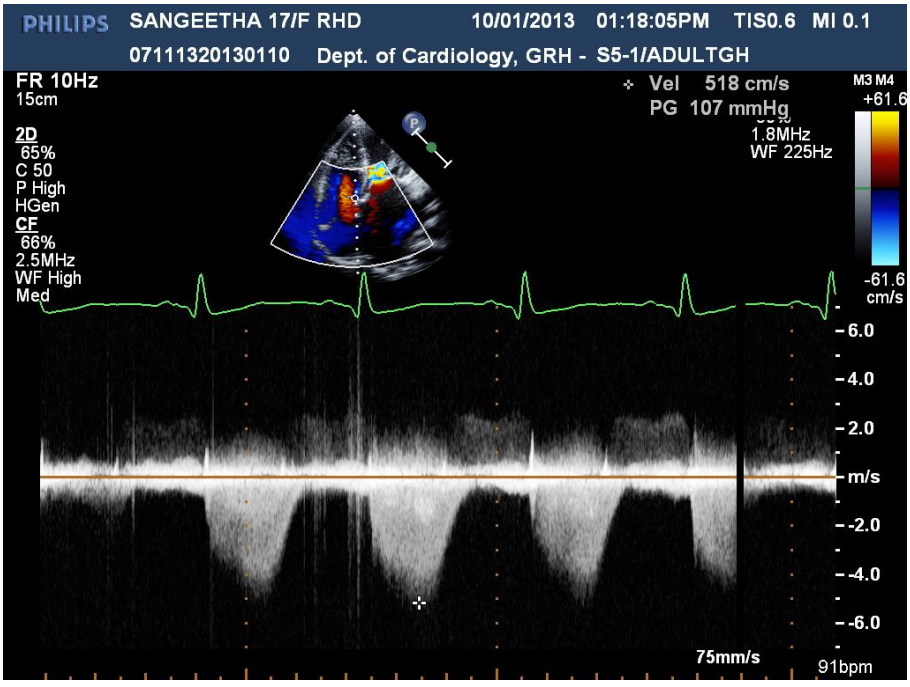
Pulmonary valve M-mode: Flying W sign



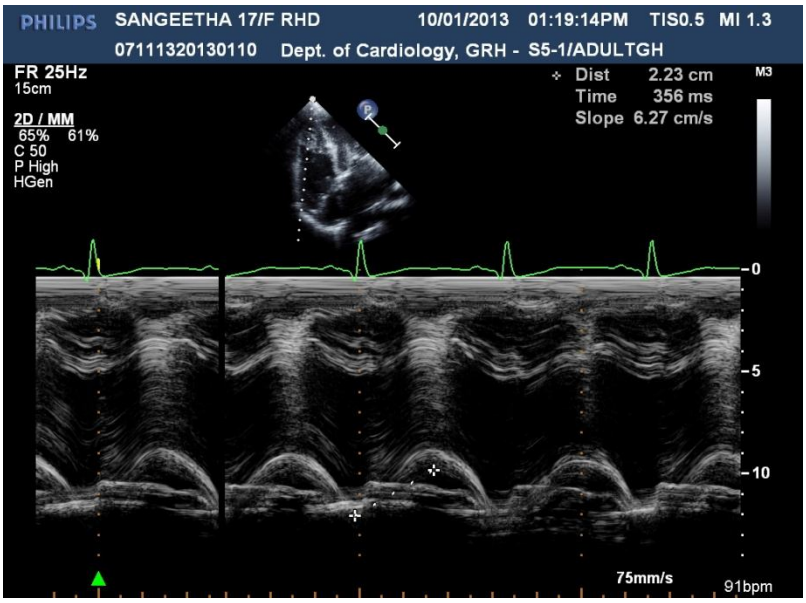
Pulmonary regurgitation



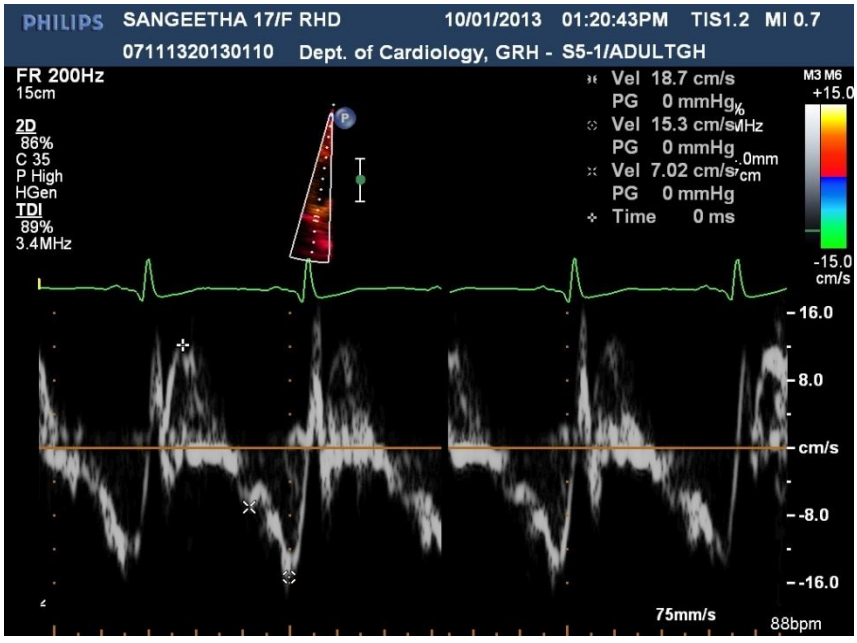
Tricuspid regurgitation



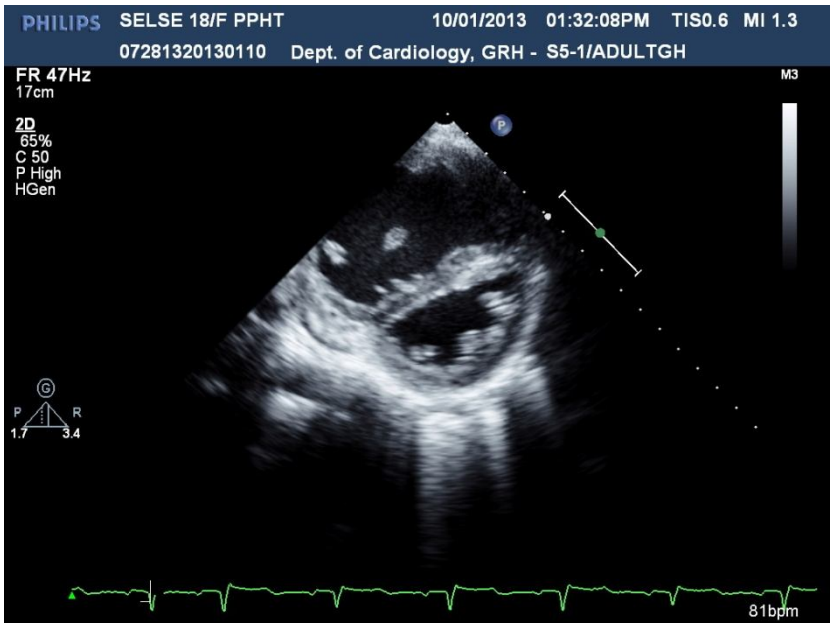
Tricuspid regurgitation continuous doppler



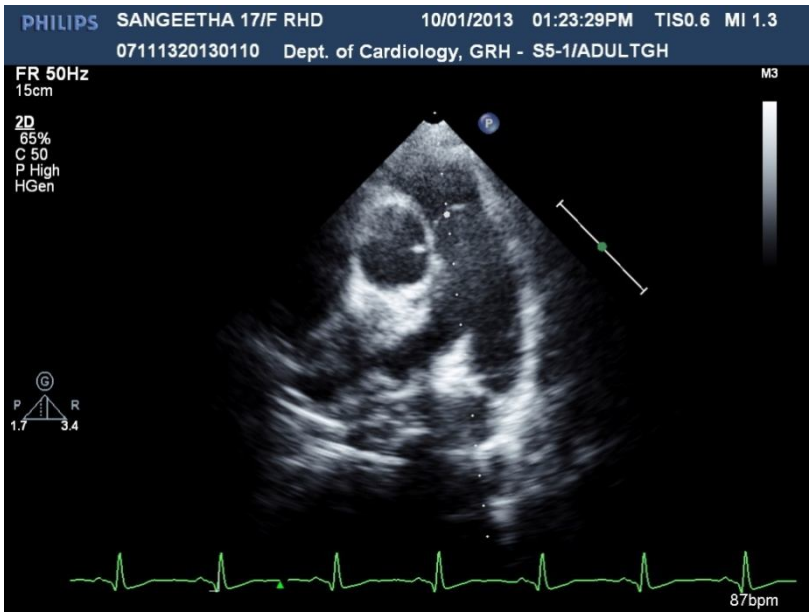
Tricuspid annular plane systolic excursion



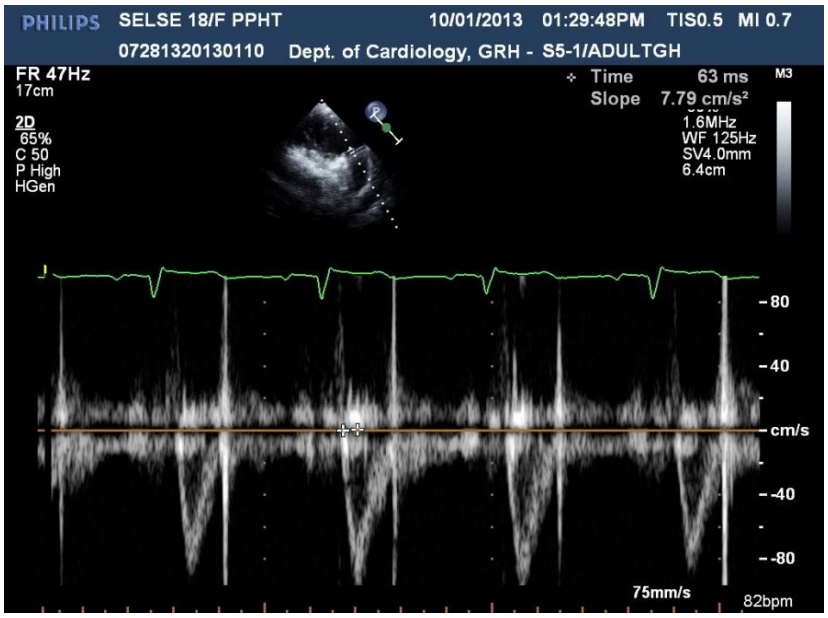
Tricuspid annular tissue Doppler velocities



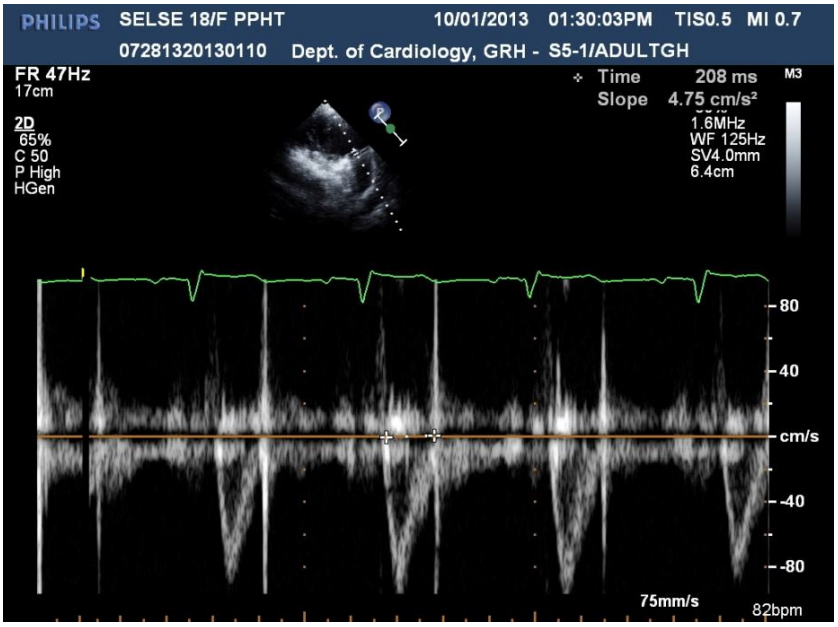
Parasternal short axis view: D - sign



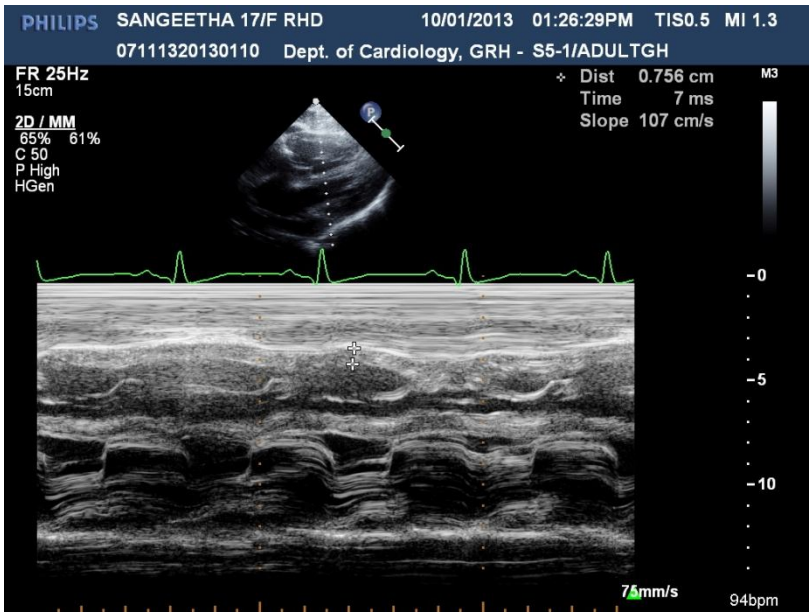
PSAX view: Dilated MPA



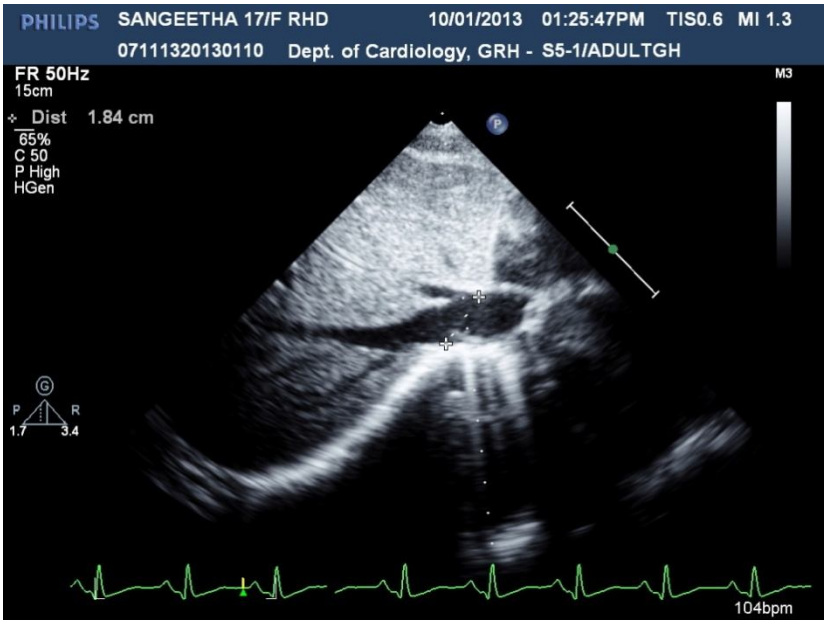
Pulmonary artery acceleration time



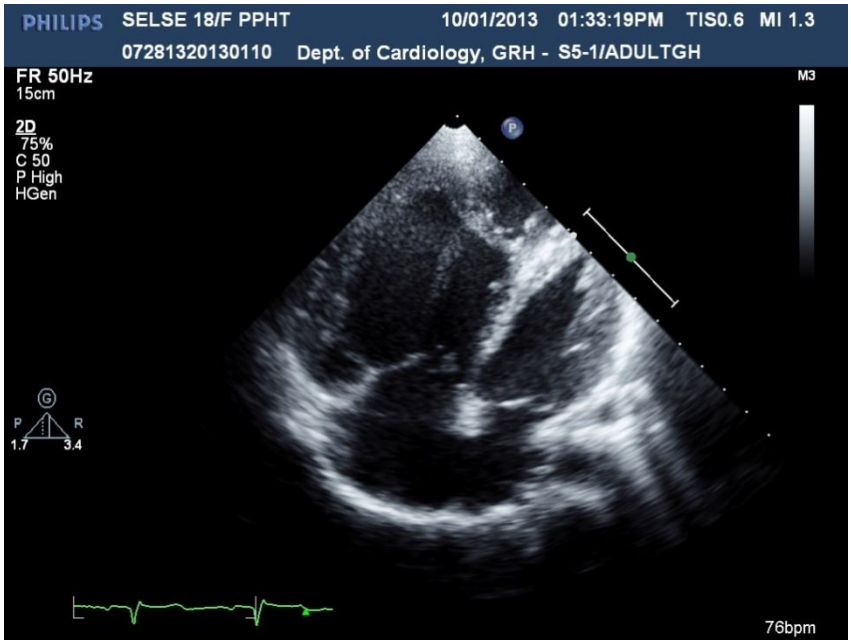
RV ejection time



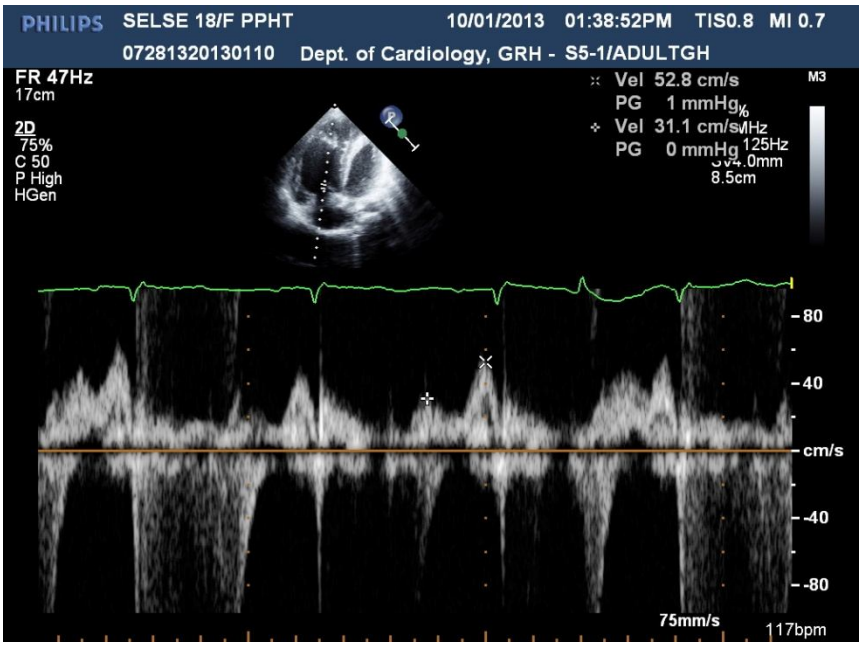
Subcostal view: Measuring RV wall thickness



IVC measurement

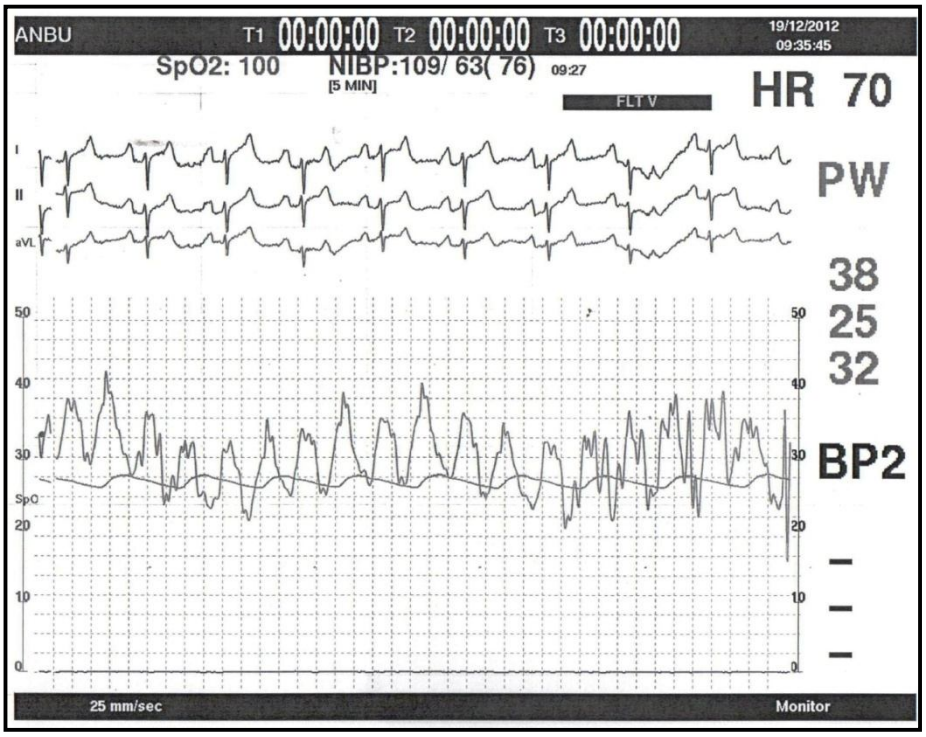


Apical four chamber view: RA, RV

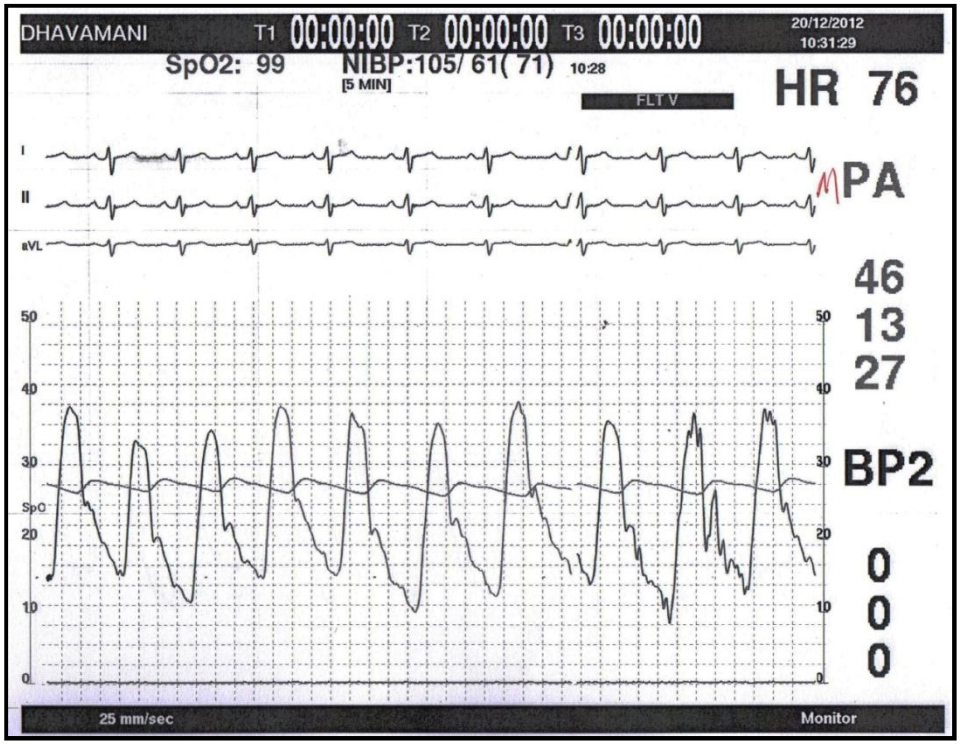


Tricuspid forward flow pulse doppler

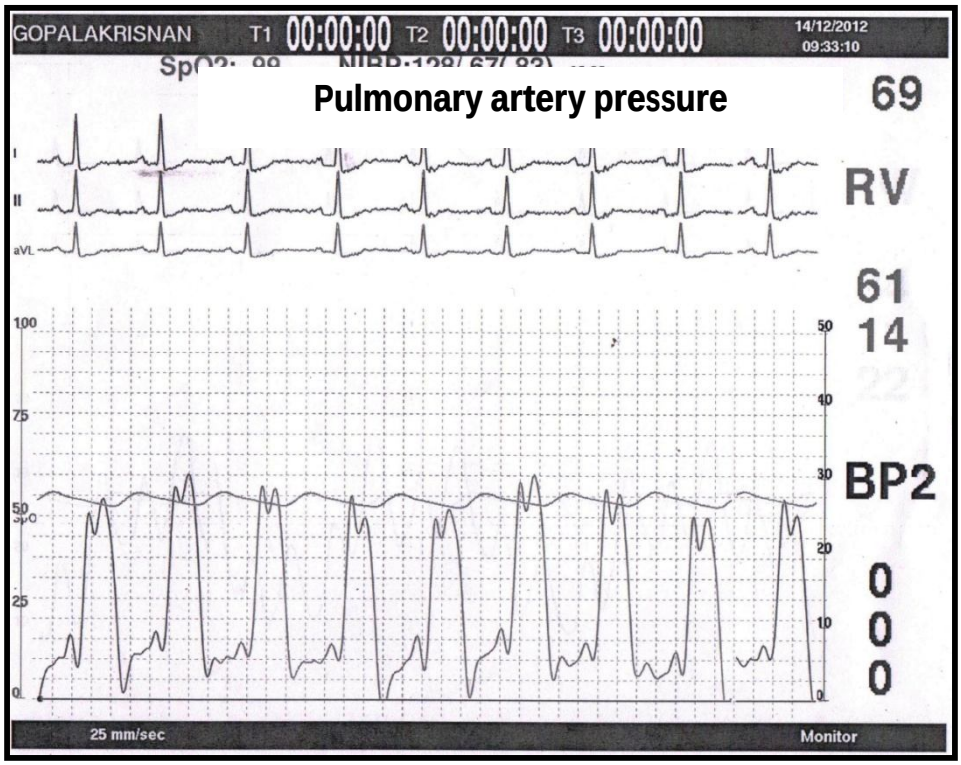
PRESSURE TRACING



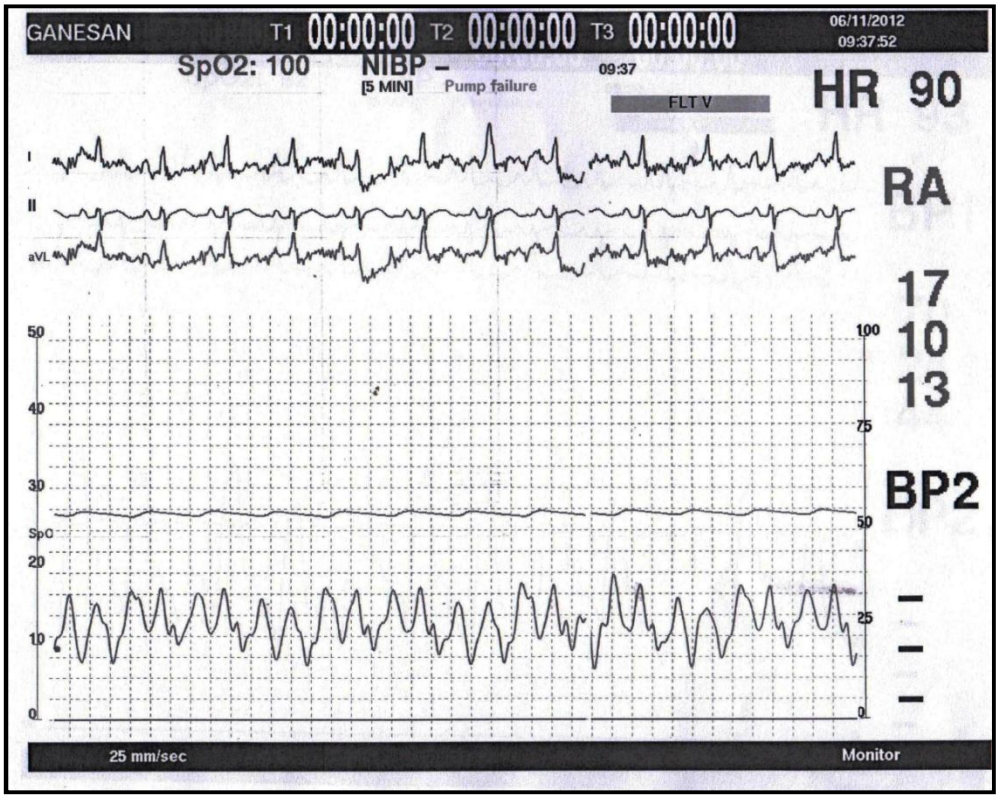
Pulmonary artery wedge pressure



PRESSURE TRACING



RV pressure



RA pressure

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INTRODUCTION Two decades ago pulmonary hypertension (PH) was seen as a serious illness with a survival of 2.8 years from its diagnosis. Significant progress has been made in this field in the last ten to fifteen years in the understanding of the pathophysiology and also the treatment of PH. In the past, even though physicians diagnosed PH, treatment of this condition was not rewarding and patients almost always succumbed to the disease. The discovery of prostacyclin by Sir John Vane has since made a revolution in the treatment of PH1. PH is a disease that results from reduction in the quantity of blood flowing across the pulmonary circulation, that causes an increase in pulmonary vascular...